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Corrosion

An Official Monthly Publication of the NATIONAL ASSOCIATION OF CORROSION ENGINEERS

Volume 3 **JANUARY, 1947** **Number 1**

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Subscription: $5.00 per year to non-members. Member's dues $7.50, of which $3.00 is for a year's subscription to CORROSION. Additional single copies to members 50 cents, to non-members 75 cents. Publication office, 905 Southern Standard Building, Houston 2, Texas.

Application for entry as second-class matter is pending

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Laboratory Aid—AVAILABLE TO HELP YOU FIGHT CORROSION

A major activity of the INCO Research Laboratory at Bayonne, New Jersey, is the study of corrosion.

While field tests are often to be preferred when selecting a metal for some specific purpose, laboratory tests are much better for studies of a more fundamental nature such as the principles of galvanic corrosion . . . *or for extending the data obtained from field tests.*

In these roles, INCO laboratory research takes various forms.

Controlled Conditions

On some occasions, corrosion tests are carried out under controlled conditions to simulate actual service when it is not feasible to make plant tests.

In other instances, the Laboratory can be used to establish which of several factors is of *controlling* importance in a given corrosion problem. Sometimes, too, laboratory testing is needed to explain anomalies that cannot be investigated satisfactorily by further field testing, e.g., effects of impurities in process liquors.

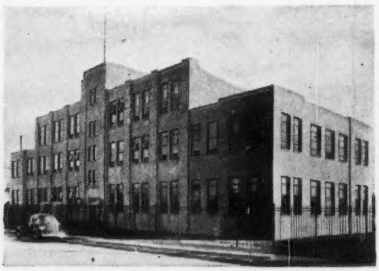
Laboratory testing is extremely helpful after field tests have been carried to a point requiring isolation and separate study of individual factors such as aeration, temperature and velocity.

Laboratory Examination

Another phase of the Laboratory's work is the examination of materials or parts that have corroded in service. Here, trained corrosion engineers and laboratory technicians examine the specimen to determine the nature of the attack, the probable mechanism of corrosion, and the presence of any correctible causes of sub-normal corrosion resistance.

Reliable Recommendations

Such complementary testing makes possible reliable recommendations of how to minimize corrosion in service and how to select the metal or alloy best able to perform under the influence of the dominating factor (or factors) revealed.



Main Research Laboratories of The International Nickel Company, at Bayonne, N. J. A separate section is devoted to corrosion research.

One type of apparatus used at the Bayonne laboratory for control of motion, temperature and aeration in immersion corrosion tests.

Thus, INCO laboratory testing and INCO field testing work hand in hand in the fight against corrosion.

The two types of testing always should be considered complementary . . . not competitive. Very often *both* are necessary for a complete understanding of the corrosion problems brought to INCO.

INCO TRADE MARK

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York 5, N. Y.

(No. 4 in a series describing the corrosion research program of THE INTERNATIONAL NICKEL COMPANY.)

Results Obtained From Five Years of Cathodic Protection on 24-inch Gas Line Rapidly Deteriorating From Bacterial Corrosion

By Wm. E. Huddleston
Consulting Engineer, Huddleston Engineering Co., Bartlesville, Oklahoma.

DURING the past ten years a considerable amount of interest has been manifested in the study and mitigation of microbiological anaerobic corrosion. Mr. Raymond F. Hadley (1)(2)(3) and Professor T. D. Beckwith (4) have conducted extensive research work in connection with the study of this type of corrosion and have published invaluable information relating to the theory and mechanism involved in the process of anaerobic corrosion.

The discussion presented in this paper relates to a five-mile section of 63.413-pound, 24-inch, welded gas transmission line having a wall thickness of 0.250 inch and laid in the year 1930. The line was coated with a commercial tar enamel, but was not wrapped.

Figure 1 shows a right-of-way plat of the line. The corrosive areas of primary concern are the single line crossing on the North Canadian River, and the mile long section of pipeline that is situated in the poorly drained grass swamps. The swampy area is water saturated during at least 75 percent of the year, and possesses high electrical conductivity. The top soil becomes extremely consolidated during the dry season of the year. A general view of the right-of-way through this area may be seen in Figure 2 and in Figure 3. The North Canadian River carries a considerable quantity of sewage disposal, and the water normally measures high in specific conductivity.

The first external corrosion leaks developed in the swampy area approximately ten years after the line had been placed in service, and the leak frequency reached a maximum during the eleventh year of service. During the course of installing leak clamps, the pipe was observed to be generally pitted over the top and sides and slabbed along the bottom. Because of the poor condition of the line, it was decided to patch weld the pipe in the leak bell holes only, and investigate the possibilities of installing cathodic protection in order to forestall leakage on the remainder of the line.

After having completed the patch welding, the usual tests for galvanic corrosion, cathodic interference and electrolysis failed to account for such an enormous amount of pitting during the comparatively short time that the line had been in service. The line was found to be well insulated from foreign sources of interference by the presence of insu-

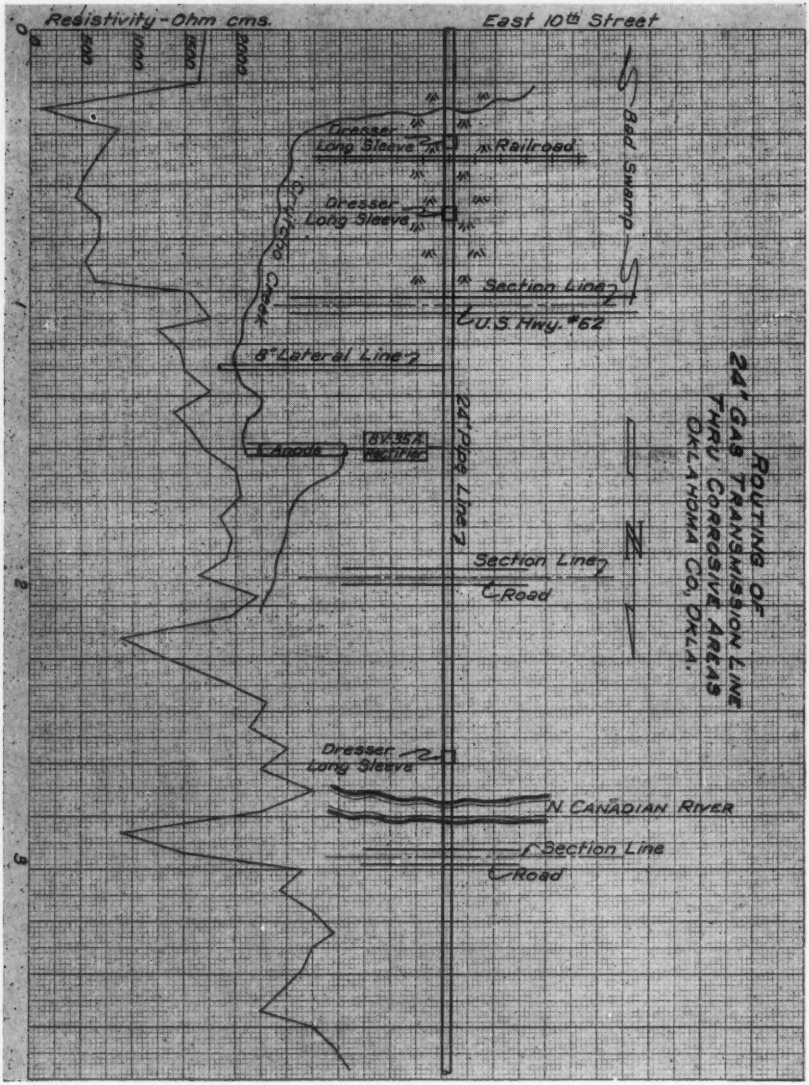

Resistivity - Ohm cms.
East 10th Street
0
200
1000
2000
Dresser Long Sleeve
Railroad
Bad Swamp
Dresser Long Sleeve
Section Line
U.S. Hwy. #62
8" Lateral Line
Deep Creek
24" Pipe Line
6V-35A Rectifier
Section Line
C. Road
Dresser Long Sleeve
N. CANADIAN RIVER
Section Line
C. Road
ROUTING OF 24" GAS TRANSMISSION LINE THRU CORROSIVE AREAS OKLAHOMA CO. OKLA.

Figure 1.

Figure 2—General view of right-of-way, showing swamp through which line passes.

lating couplings, as seen in Figure 1. Prevailing long line and/or short line currents were of such small magnitude that they were hardly measurable. Accordingly, the possible existence of anaerobic corrosion was considered, and the line was uncovered in a number of other locations for further inspection and study.

Close examination revealed that the pits were filled with a dark brown substance that was subsequently identified as being iron sulfide (3). This simple test furnished the first clue to the corrosion trouble, and to further substantiate our supposition, we investigated other factors that supposedly influenced the optimum growth of the sulfate reducing bacteria. The 24-inch line had a normal coverage of 48 inches, which would encourage the growth due to the favorable temperature ranges at that depth (4). The soil was found to contain a light concentration of sodium chlorine, the source of which was salt water disposal from the Oklahoma City field. At that time, the significance of this

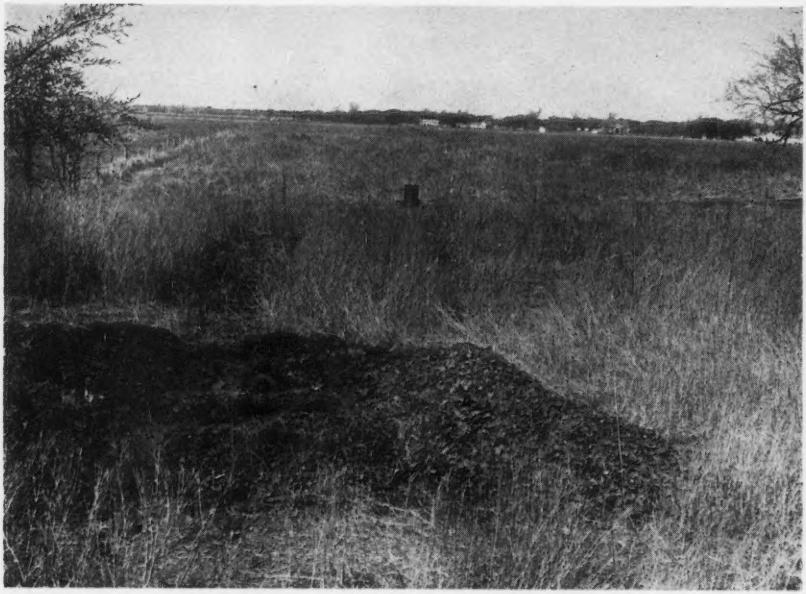


Figure 3—Another view of right-of-way.

factor was questionable in attempting to establish proof of the presence of anaerobic bacteria (4).

Simultaneous with the foregoing investigations it became necessary to uncover and lower a short section of the line on one side of the North Canadian River because of erosion. While the line was stripped, a routine inspection was made of the pipe surface. Close examination disclosed innumerable deep pits, some of which were two-thirds of the way through the pipe wall. Here, too, the corrosion products consisted mostly of iron sulfide, the pipe was of sufficient depth to maintain a temperature range favorable for bacterial growth, and the water was found to contain a small amount of sodium chlorine. The pipe was pit welded before being lowered and backfilled, and no excavations were made on the remaining portion of the river crossing.

In view of the foregoing disclosures, it was agreed that immediate action must be taken if extensive pipe repairs and replacements were to be forestalled.

Hadley (2) advanced the hypothesis in the conclusions of his early studies on the subject of anaerobic corrosion that, "the basic theory underlying the microbiological corrosion process is in accordance with the more commonly accepted electrochemical theory of corrosion, the principal differences being the manner by which the cathodic hydrogen polarization is removed, and the mechanism causing suppression of

Figure 4—Condition of protective coating before removal to inspect pipe. Areas circled are breaks made with digging tools.

the ferrous ions." At that time Beckwith (3) had concluded that the value of cathodic protection in arresting anaerobic bacterial corrosion was controversial.

In the absence of definite information on the efficacy of cathodic protection used to combat bacterial corrosion, the decision was made to install rectifying equipment in an attempt to reduce the leak frequency. Accordingly, a 35-ampere cathodic rectifier was installed at a location that was considered most favorable for reaching the river crossing to the North and also the grass swamps to the South. Pipe-to-soil potentials well in excess of 1 volt were immediately established over the entire river crossing and throughout the grass swamp, when the rectifier was adjusted to its rated full load and capacity. With the exception of one two-day interruption caused by a lightning surge, the protective unit has operated continuously for more than five years.

The leak frequency was, of course, at a maximum during the eleventh year following construction of the line. Pit-hole leaks were developing at scattered locations at the rate of a leak every ten to fifteen days, and on each repair the pipe was found to be excessively pitted. As previously stated, the pipe was patch

Figure 5—Close-up showing condition of protective coating. Areas circled are breaks made during excavation.

welded in the leak bell holes only, the total footage of which represents only six percent of the total amount of the 24-inch pipeline that is situated in the extremely corrosive sections.

A total of only six pit-hole leaks developed during the 26-months following the installation of the rectifier. This was a substantial reduction in the leak frequency over the same period prior to installation of the rectifier. All six leaks occurred in new locations, that is, in locations that had not previously been spot welded.

No pit-hole leaks have occurred during the past three years, which lends encouragement to the possibility that all corrosive action has been suppressed on this 24-inch pipeline. The six pit-hole leaks that occurred during the 26-months following the installation of cathodic protection were apparently at locations that had virtually reached full penetration of the pipe wall by the time that cathodic protection was established.

The 24-inch pipe was recently excavated at two locations within the swampy section and the protective coating was removed to facilitate a thorough inspection of the pipe surface. The inspection sites were selected at random, and in both cases the pipe was found to be in good condition. Figure 4 and Figure 5

Figure 6—Pipe surface within small area where coating has been removed.

show the condition of the protective coating before it was removed to permit inspection of the pipe. The areas circled with chalk are breaks that were made with digging tools during excavation of the line. Figure 6 shows the excellent condition of the pipe surface within a small area where the coating had been removed.

Conclusions

A study of the field conditions that prevailed on the 24-inch pipeline at the time leaks first developed, definitely indicated that the excessive amount of pipe deterioration was attributed to microbiological corrosion. The fact that pit-hole leaks have been virtually eliminated at the close of a 62-month period in which cathodic protection has been applied, leads to the conclusion that excellent results may be obtained in combating microbiological corrosion by the use of cathodic protection.

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Corrosion Ratings for Metals

By H. D. Holler and R. A. Frye
Westinghouse Electric Corporation, East Pittsburgh, Pa.

ONE of the chief characteristics of the electrical manufacturing industry is its great diversity of products. Some of its products, of course, are not usually exposed to a corrosive environment, but in the manufacture and use of many of them, corrosion problems of all kinds are encountered. The design engineer is expected to anticipate such problems, and to select the most suitable materials. It is, therefore, important that useful information on the corrosion-resistant properties of materials be available to him.

In designing any structure, he must consider all known factors affecting its useful life and also try to make some provision for unforeseen circumstances. He uses the existing data on the properties of materials and computes the size and shape of the parts, allowing a safety factor to provide for uncertainties in the accuracy of the data and for abnormal conditions of use, such as overloading, accidents and abuse. Insofar as data on physical properties are concerned, there are many available sources. For example, the mechanical, electrical, magnetic and thermal constants are summarized in handbooks, engineering reports and published papers. By the use of such data in mathematical equations, it is possible to estimate the probable performance of the structure with considerable accuracy.

In the field of corrosion, however, we do not have constants that can be used in such a quantitative manner. Regardless of the voluminous literature on the corrosion of most of the common materials, it is a stubborn fact that the corrosion resistance of any material for a particular application can be definitely determined only by exposing it to the required operating conditions. That is, the selection of materials should be based on first-hand experience.

In attempting to predict the probable corrosion resistance of a material under given service conditions, we have to consider the influence of both physical and chemical factors. Even if someone were to develop an equation expressing the rate of corrosion in terms of such factors, it would be of little practical use because of the impossibility of evaluating all of the factors. Changes in conditions, like the concentration and temperature of a chemical solution, may increase or decrease the corrosive attack in an unpredictable manner. Thermodynamics may tell

us whether corrosion of a certain metal in a given environment may occur, but furnishes no hint as to the rate of attack.

What is more important than rate of corrosion, in many cases, is the type, or pattern of attack, and the nature of the corrosion product. For example, the rate, in terms of weight-loss of metal per unit area, may be low, but if this loss is localized at a few points, the damage may be enormously greater than the weight-loss would indicate. Thus, in tanks and pipelines, the pitting type of corrosion may destroy their usefulness as such, while in a highly stressed airplane part, a corrosion crack may lead to distressing consequences. In either case, the actual loss of metal may be negligible. On the other hand, if the initial corrosion-product is uniformly adherent, there may be an apparent weight-gain, and such coating may stifle further corrosion to such an extent that it is really protective. It is for this reason that many published corrosion rates, expressed in terms of weight-loss or weight-gain per unit area, are of little practical use to the design engineer.

It seems obvious, therefore, that corrosion resistance can not be expressed in a simple manner like most other properties, such as electrical resistance, or tensile strength. If we were to assign values of corrosion resistance to metals for all possible combinations of conditions, we would have an almost infinite number of ratings. Their tabulation in a useful form would certainly not be practicable. The idea of tabulating corrosion ratings need not be dismissed entirely, however, if we are willing to restrict conditions to such a degree that they may be reasonably well defined. The restriction and definition of conditions depend largely on opinion and judgment. For example, the conclusions reached by certain groups of investigators, such as ASTM, represent the consensus of opinion on data obtained under defined conditions. Any tabulated ratings of corrosion resistance based on such data represent the composite judgment of specialists. The value of such ratings depends on limiting their use to the specified conditions. This means that the design engineer must ascertain the conditions of use, and determine for himself whether the tabulated ratings should be applied. Herein lies the danger in the use of such ratings, because it is frequently impossible to ascertain all of the conditions. If the available evidence indicates conditions of serious or doubtful character, then the selection of material is not a handbook problem for the design engineer, but an experimental problem for the chemical engineer.

Fortunately, most of the products of the electrical industry are not exposed to chemical solutions. When the engineer meets the problem of selecting a metal for use in a chemical solution, he should consult some source of first-hand experience, such as the supplier of the material, or the customer, and not attempt to get the answer solely from any table of corrosion ratings. This suggestion holds true to a special degree in the case of exposure to waters. Since all waters contain various amounts of dissolved substances, they are essentially chemical solutions of widely different corrosive properties.

In the development of our corro-

sion ratings on such a large number of standard materials, it was, of course, impracticable and unnecessary to carry out an experimental program. Instead, we have relied upon our suppliers, who have the background of information necessary to substantiate the ratings given in the accompanying tables. We have attempted to specify conditions and define their ratings in a manner which, it was hoped, would be of practical value to the design engineer.

We have included ratings in sea waters because the problem of selecting material for use in sea waters very frequently arise. We do not feel sure that ratings should be tabulated since its corrosiveness depends greatly upon its natural composition and various contaminants. However, since ratings were furnished by the suppliers, they are tabulated as a preliminary guide. If the consequences of corrosion might be very serious, the problem should be considered in the same category as chemical solutions and handled accordingly. It is, therefore, a question whether the proposed corrosion ratings for sea waters should be retained here.

Corrosibility differs from other properties in that it depends upon the corrosiveness of the environment, which is frequently very difficult, or impossible to define. Through common effort, we have developed a general understanding regarding tvpical atmospheric environments. For example, ASTM has designated them as "rural," "industrial," or "marine." Industrial cities along the coast may have an "industrial-marine" atmosphere. There is a great deal of published information on the resistance of materials to these typical atmospheres, and ratings given here are based upon the consensus of opinion, represented by ASTM and the suppliers, who furnished this information. Thus, we know from general experience, in a given location, say "industrial," materials of several degrees of corrosion resistance are available. Therefore, for this location, such materials may be rated A, B, C, etc., entirely without any other definition of corrosiveness. From a practical standpoint, it is, therefore, feasible to evaluate corrosibility and enable the design engineer to make an intelligent choice.

For a different location, which may be "industrial" also, someone's judgment must influence a decision as to whether the ratings still hold. Conservatism would require that conditions be assumed to be no less corrosive in the different location, and that selection be made accordingly.

In requesting corrosion ratings from our suppliers, it was hoped that each rating would have the same meaning among the various kinds of materials. For example, a ferrous alloy, rated A in a given atmosphere, might then be equivalent to a non-ferrous one rated A, insofar as corrosion is concerned. To accomplish this result, all of the ratings were exchanged among the various suppliers and, in some cases, revised. The proposed ratings A, B, C, D, E seemed sufficient for grading all available materials, but the suppliers were willing to go still further, utilizing positive and negative signs. It must be definitely understood that comparisons among different materials should be limited

to the vertical, that is, for a given condition; for example, "rural." It is not fair to compare ratings for different conditions. For example, material X might be better than Y for industrial conditions, but inferior to Y in a marine atmosphere.

In establishing these ratings, consideration was given to the pattern of corrosive attack that may characterize certain materials. For example, tendencies toward pitting, stress corrosion, dezincification, etc., are reflected in the ratings. The possible effect of corrosion upon the functioning of the parts within a structure is the prime consideration. Tarnishing, or other slight changes in surface appearance, are considered of secondary importance. Uniformly distributed corrosion may be practically harmless in its effect upon the usefulness of the material, depending upon the character of the corrosion-product. For example, it might be adherent or loose, conducting or insulating, hygroscopic or moisture resistant.

This brings up the question of protective coatings. The ratings given here refer to bare metals only. In many applications, the low ratings of an alloy may be compensated by the use of a suitable coating for the conditions of use. For example, ordinary steel, properly coated, may be used instead of the more expensive alloys. The rating of protective coatings, however, was not included in this undertaking.

In conclusion, it is believed that tabulated corrosion ratings are useful for a number of materials under specific conditions. However, for some of our products we have to combat conditions which are very difficult to define. This requires careful testing in the laboratory and in the field by engineers primarily concerned in these applications. This project was undertaken in cooperation with the suppliers, since it was important to both of us that the most suitable materials be selected for the manufacture of our products. If we have added to the assurance of this result, our effort will have been worthwhile. It is believed that further efforts toward the translation of corrosion data into a form useful to the consuming industries are needed.

In conclusion, the authors would like to extend their appreciation to the International Nickel Company, the Aluminum Company of America and the American Brass Company for their cooperation in helping to compile the information on the appended corrosion tables. Copies of these tables may be obtained upon request from the Engineering Laboratories and Standards Department, Westinghouse Electric Manufacturing Corporation, East Pittsburgh, Penna.

Note—A discussion on this article follows the corrosion-rating tables.

INTRODUCTION TO TABLES
CORROSION RATINGS OF METALS

As a guide to the selection of materials for use under corrosive conditions, it is desirable to know the relative corrodibility of available materials. The first step toward such a selection is to ascertain the condition to which the electrical equipment will likely be exposed; next define these conditions if possible; and finally, compare the corrodibilities of different materials under these conditions.

In comparing the corrodibilities of metals and alloys it is necessary to consider the pattern of the attack and the extent of damage to the equipment. If the corrosion occurs in the form of pitting, or intergranular attack, the damage is certain to be more serious than if it were uniformly distributed over the surface. The actual loss of metal, expressed in terms of weight loss per unit surface area, is therefore not necessarily a measure of the damage done. For example, the loss of metal resulting from the pitting of a tank, or the intergranular attack of a highly stressed airplane part, is negligible as compared with the possible damage.

The engineer is concerned chiefly with any type of corrosion which may interfere with the functioning of parts. On this basis, tarnishing, for example, would not usually be considered as a serious type of corrosion, and is ignored here.

In using the ratings given here it is important that consideration be given to the form in which the metal is to be used; that is, whether as a sheet, casting or forging and also that the engineer try to visualize the possible damage caused by the more vicious types of corrosion, such as deep pitting or intergranular attack. In connection with the latter form of corrosion, the engineer is warned that consideration should also be given to the possible serious effects of internal and applied stresses, particularly cyclic stresses on the fatigue strength of metals and alloys in corrosive atmospheres. That is, when fabrication or design produce such stresses in the material, necessary steps, such as proper annealing or redesign, should be taken to reduce the possibility of damage.

It is not possible to include all these factors within the meaning of the following tabulated ratings and it is not so intended. The selection of a metal or alloy for a corrosive situation is largely a chemical engineer's problem. The ratings here given are intended as a guide to further investigation and not to final selection.

DEFINITION OF CONDITIONS

In Chemical Solutions:

Corrosion is an exceedingly complex process. The expression of an opinion on the probability of corrosion is similar to weather forecasting. Having determined all apparent conditions, an intelligent opinion may be given; but if certain conditions are overlooked or varied in the meantime, the results may not be as predicted. For example, when a metal is exposed to a chemical solution, we must consider the effects of many factors, vis., concentration, temperature, movement and aeration of the solution as well as stresses, surface conditions and purity of the metal. The selection of materials for use in chemical solutions is a specialized problem for the chemical engineer and can be made only on the basis of information available to him. The information required is usually too complex to allow putting into the form of tables; and the tables herein must not be so used.

In Natural Waters:

Fresh waters vary tremendously in corrosivity, depending upon their natural source, whether lake, river, or underground, and upon contaminating sources such as mines, sewage, and industrial wastes. Since natural waters contain many impurities affecting their corrosivity, they should be considered in the same category as chemical solutions and the selection of materials for use in contact with them is a chemical engineering problem. Since water-cooling systems are common accessories to electrical equipment, the problem of selecting the least corrodible materials frequently arises, and can be intelligently made only on the basis of the information and experience available to the engineer. It is extremely important that the engineer interpret the analysis of the water and survey the possibilities of its contamination with corrosive agents, like acid mine water. This involves the question of water-treatment and the use of corrosion inhibitors.

In Various Atmospheres:

In the case of equipment to be used in a certain atmosphere, the question of selecting materials is less complex than it is for handling chemical solutions. The suppliers have accumulated information on comparative corrosion resistance in typical outdoor air and also in certain chemical vapors commonly encountered in industrial processes; and have furnished corrosion ratings under these conditions. Under "General Outdoor Air" we have three general classes of atmosphere, namely Rural, Urban and Marine. Frequently, it is difficult to classify an outdoor atmosphere. For example, the atmosphere in a city along the sea coast would have an "Urban" or "Marine" composition and the corrosion rating should be taken as the worse of the two.

While it is intended that comparisons in ratings should be made only in vertical columns, that is, for given conditions, the tendency toward making comparisons along horizontal lines is hard to resist. If we limit such horizontal comparisons to atmospheric conditions, it is believed that generally useful conclusions may be reached. For example, if a material has an AB rating in

general outdoor city air, and it also has a lower rating in a certain "Specific Industrial Atmosphere," it is very important that the engineer survey the possibilities of contamination of the air from the surroundings. This is particularly true of copper alloys, since they are adversely affected by many chemical vapors. Such precautions as protective coatings and air conditioning may then be considered.

Corrosion Due to Galvanic Couples

When two metals are in contact and this contact becomes wet with a conducting solution, there is an electric potential set up between them. For example, if magnesium touches silver, both being in an electrolyte, a difference in potential of more than a volt may exist between the two metals. (See Figure "A".) Likewise, if different metals and alloys are successively brought into contact with silver or any other metal, they will exhibit a characteristic potential, and may be listed as in the table on page 15. It is dangerous to use metals in the upper end (anodic end) of the list in contact with those in the lower (cathodic) end, without safeguarding such a contact by coating or other means, to keep it from being wet with a conducting solution. For example, in sea water, which is an electrolyte of high electrolytic conductivity, galvanic potentials should generally be avoided. This is true especially with the alloys of aluminum and magnesium, iron, steel, and high-zinc brasses, in contact with copper. If, however, the area of the corroding (anodic) metal is very large as compared with the cathodic copper, the corrosion will be spread over this large area, and the actual damage will be mitigated. For example, copper pipe is usually connected to steel tanks without serious results; but the connection of steel pipe to a copper tank would result in a different story. The anodic metal will suffer accelerated corrosion to an extent determined by the corrosivity of the environment, the area of the cathodic metal and the resistance of the galvanic circuit, which consists of the two metals and the solution.

Passivity

Sometimes, galvanic couples do not result in corrosive attack of the anodic metal, as might be expected. The condition, which prevents the expected attack, has been named "Passive" but has received no universally accepted explanation. Alloys containing chromium are most pronounced in their passivity, which accounts for its wide use in corrosion-resistant alloys. Passivity also depends upon the nature of the solution. If the solution is one which destroys passivity, the alloy is then said to become "active" and will be attacked. In the table on page 15, these active-passive alloys are designated in three groups, A, B, and C, which under certain conditions become "active" and are placed higher in the list. It is obvious that the conditions of use must be investigated before a "passible" metal or alloy is recommended. When in doubt as to whether an active-passive material will be active or passive—assume that it will be active if its area is relatively small, and passive if its area is relatively large.

THE ELECTROMOTIVE SERIES

ANODIC END
Magnesium
Magnesium Alloys
Zinc
Aluminum 2S
Cadmium
Aluminum 17ST
Carbon Steel
Copper Steel
Cast Iron
4-6% Cr Steel

A { 12-14% Cr Steel, 16-18% Cr Steel, 23-30% Cr Steel } Active

Ni-Resist

B { 7 Ni-17% Cr Steel, 8 Ni-18% Cr Steel, 14 Ni-23% Cr Steel, 20 Ni-25% Cr Steel, 12 Ni-18% Cr-3% Mo Steel } Active

Lead-Tin Solder
Lead
Tin

C { Nickel, 60 Ni-15% Cr, Inconel, 80 Ni-20% Cr } Active

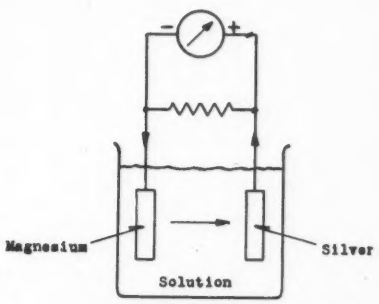
Brasses
Copper
Bronzes
Nickel Silver
Copper Nickel
Monel

C { Nickel, 60 Ni-15% Cr, Inconel, 80 Ni-20% Cr } Passive

A & B { 12-14% Cr Steel, 16-18% Cr Steel, 7 Ni-17% Cr Steel, 8 Ni-18% Cr Steel, 14 Ni-23% Cr Steel, 23-30% Cr Steel, 20 Ni-25% Cr Steel, 12 Ni-18% Cr-3% Mo Steel } Passive

Silver
Graphite
Gold
Platinum
CATHODIC END

FIG.A



Arrow indicates direction of current.
Inside cell, from anode to cathode.
outside cell, from cathode to anode.
A meter indicates cathode to be positive + and anode negative −

NOTE: The following should be avoided:

1. Combinations of materials from different subgroups.

2. Combinations from extreme ends of subgroups.

   (a) When the area of the metal higher in the list is smaller than that of the metal lower in the list.
   The higher metal will suffer accelerated corrosion to an extent determined by the corrosivity of the environment, the area of the more noble metal and the resistance of the electrical circuit.

   (b) When in doubt as to whether active-passive materials will be active or passive, assume that it will be active if its area is relatively small and passive if its area is relatively large.

TABLE I

Corrosion Ratings of Commercial Alloys of Aluminum and Magnesium

(Data by courtesy of the Aluminum Co. of America)

MATERIAL	Alcoa Designation	Typical W.E.& M.Co. Material (P.D. Spec.)	GENERAL OUTDOOR AIR		
			Rural	Urban	Marine
ALUMINUM AND ALUMINUM ALLOYS					
99% Al	2S	7601	A	B	B
Al.—Mn	3S	7602	A	B	B
Al.—Cu—Mg—Mn	17S	7603	B	B	C
Al.—Cu—Mn—Mg	24S	8490	B	B	C
Al.—Cu—Mn—Mg	24C2	8538	A	B+	B+
Al.—Si	43	4458	A	B	B
Al.—Si	13	4257	A	B	B
Al.—Cu—Si	195	32*	B	B	C
Al.—Cu—Si	C113	5298	B	B	C
Al.—Cu—Fe—Zn	112	12	B	B	C
Al.—Si—Cu—Mg	355	40	A	B	B
Al.—Si—Mg—Cr	53ST	5859	A	B	B
Al.—Mg—Cr	52S	7250	A	B	B
Al.—Mg—Si—Cu—Cr	61S	....	A	B	B
MAGNESIUM AND MAGNESIUM ALLOYS					
99.8% Mg	AM2S	3033–7751	C	D	D
98% Mg—1.5% Mn	AM35	....	B	C+	D+
95.8% Mg—3% Al.—1% Zn—0.2% Mn	AM52S	....	B	B	D+
88.8% Mg—9% Al.—2% Zn—0.2% Mn	AM260	....	B	C	D
90.8% Mg—6% Al.—3% Zn—0.2% Mn	AM265	....	B	C	D

* Not to be used without heat treatment.

Aluminum alloys are used in ammonia and in hydrogen sulfide vapors but are not recommended for other corrosive atmospheres. These alloys may also be used in various concentrations of acetic, nitric and chromic acids. The scaling temperature of aluminum alloys is above their melting points. With the exception of zinc, aluminum and magnesium alloys should not be used in contact with other metals, if the contact is likely to get wet, unless an insulating coating be used to prevent galvanic corrosion. Magnesium alloys are not recommended for use in corrosive atmospheres. They are used in solutions of caustic alkalies, alkaline salts, and chromic acid. Magnesium alloys are not recommended for use above 400° F. because of effect of temperature on mechanical properties.

LEGEND, TABLE 1

A—Practically complete resistance, or the alloy is the best of materials within its class.

B—Good resistance, as proven by being in common use. May replace materials given A rating to secure some other advantage.

C—Adequate resistance under favorable conditions which should be investigated beforehand.

D—Sufficient resistance if adequate precautions are taken to reduce effect of corrosive conditions, as by coatings, cathodic protection, re-design, etc., or where appearance is not important and appreciable corrosion may be provided for, or tolerated.

E—Poor resistance—use only if no better material is available.

Plus and minus signs are used to permit a better differentiation between the corrosion-resistant qualities.

WESTINGHOUSE RECOMMENDATIONS

A & B—PROBABLY safe to use

C—Use only with CAUTION

D—Use should be avoided unless protected or unless appreciable corrosion can be tolerated, or provided for.

E—Use should be AVOIDED

Provisional Corrosion Ratings† of Commercial Alloys of Aluminum and Magnesium in Sea Water of Table I.

Material	Alcoa Designation	Typical W. E. & M. Co. Material (P.D. Spec.)	Provisional Rating † Sea Water
ALUMINUM AND ALUMINUM ALLOYS			
99% Al	2S	7601	B
Al.-Mn	3S	7602	B
Al.-Cu-Mg-Mn	17S	7603	D
Al.-Cu-Mn-Mg	24S	8490	D
Al.-Cu-Mn-Mg	24C2	8538	B
Al.-Si	43	4458	B
Al.-Si	13	4257	B
Al.-Cu-Si	195	32*	D
Al.-Cu-Si	C113	5298	D
Al.-Cu-Fe-Zn	112	12	D
Al.-Si-Cu-Mg	355	40	C
Al.-Si-Mg-Cr	53ST	5859	B
Al.-Mg-Cr	52S	7250	B
Al.-Mg-Si-Cu-Cr	61S	....	B
MAGNESIUM AND MAGNESIUM ALLOYS			
99.8% Mg	AM2S	3033, 7751	E
98% Mg-1.5% Mn	AM35	....	E
95.8% Mg-3% Al.-1% Zn-0.2% Mn	AM52S	....	D
88.8% Mg-9% Al.-2% Zn-0.2% Mn	AM260	....	E
99.8% Mg-6% Al.-3% Zn-0.2% Mn	AM265	....	E

* Not to be used without heat treatment.

LEGEND, TABLE I (SEA WATER)

A—Practically complete resistance, or the alloy is the best of materials within its class.

B—Good resistance, as proven by being in common use. May replace materials given A rating to secure some other advantage.

C—Adequate resistance under favorable conditions which should be investigated beforehand.

D—Sufficient resistance if adequate precautions are taken to reduce effect of corrosive conditions, as by coating, cathodic protection, re-design, etc., or where appearance is not important and appreciable corrosion may be provided for, or tolerated.

E—Poor resistance—use only if no better material is available.

†Corrosion ratings for metals in contact with sea water are subject to variations, depending upon harbor water pollution and flow. Ratings given for sea water applications shall be considered as a supplement to, rather than a replacement of, other means of arriving at a proper choice of material.

TABLE II

Corrosion Ratings of Commercial Alloys of Iron, Nickel and Chromium

(Data by courtesy of the International Nickel Company)

MATERIAL	Amer. Iron & Steel Institute Type No.	Typical W.E. & M. Co. Material (P.D. Spec.)	OUTDOOR AIR			SPECIFIC INDUSTRIAL ATMOSPHERES (WET)					Scaling Temp. Deg. F. Note 1
			Rural	Urban	Marine	Ammonia	Hydrogen Sulfide	Hydrogen Chloride	Sulfur Dioxide	Chlorine	
Low Carbon Steel	....	1555 2084	D+	D	D	B	D	D	D	D	1000
Nickel Chrome	A-3135	....	D+	D+	D	B	D	D	D	D	1000
Chrome Molybdenum	A-4140	7940	D+	D	D	B	D	D	D	D	1000
Copper Bearing Steel	....	4225	D+	D+	D	B	D	D	D	D	1000
4-6% Cr Steel	502	6396	D+	D+	D+	B	D+	D	D	D	1150
12-14% Cr Steel	420	8213	B+	B	C—	A	C	D	D	D	1250
12-14% Cr 0.60% Mo	416	5161	B+	B	C—	A	C	D	D	D	1250
16-18% Cr	430	5284	A	B+	C	A	B	D	D	D	1550
23-30% Cr	446	6770	A	A	C+	A	A	D	B	D	2000
7% Ni-17% Cr	301	7670	A	A	B+	A	A	D	C	C	Not used for oxidation res.
8% Ni-18% Cr	302 303 304	4562 6478 5872	A	A	A—	A	A	D	B	C	1650
8% Ni- 18%Cr-1% Cb	347	7968	A	A	A—	A	A	D	B	C	1650
8% Ni-18% Cr-0.5% Ti	321	....	A	A	A—	A	A	D	B	C	1650
14% Ni-23% Cr	309	5758	A	A	A	A	A	D	B	C	2000
12% Ni-18% Cr-3% Mo	316	8685	A	A+	A+	A	A	C	A	B	1650
20% Ni-25% Cr	310	....	A	A+	A+	A	A	D	B	C	2000
Nickel	....	1921	A	A—	A+	C-E Note 5	B	C-B	C	B	Note 2 1900 Note 3 1000 Note 4 700
30% Ni-70% Cu	....	....	A	A—	A	C-E Note 5	C—	C+	B	C+	....
Monel	....	2718	A	A	A	C-E Note 5	B	B	C	B	Note 2 1000 Note 3 1000 Note 4 650
80% Ni-20% Cr	....	3012	A	A	A+	A	A	B	B	B	2100
Inconel-80% Ni, 7% Fe-13% Cr	....	8153	A	A	A+	A	A	B	B	B	Note 2 2000 Note 3 1500 Note 4 1000

LEGEND, TABLE II

A—Practically complete resistance, or the alloy is the best of materials within its class.

B—Good resistance, as proven by being in common use. May replace materials given A rating to secure some other advantage.

C—Adequate resistance under favorable conditions which should be investigated beforehand.

D—Sufficient resistance if adequate precautions are taken to reduce effect of corrosive conditions, as by coatings, cathodic protection, re-design, etc., or where appearance is not important and appreciable corrosion may be provided for, or tolerated.

E—Poor resistance—use only if no better material is available.

Plus and minus signs are used to permit a better differentiation between the corrosion-resistant qualities.

Note 1—Values assume substantially constant temperature operations—should be lowered for cyclic heating and cooling to an extent dependent upon the frequency and range of temperature fluctuations.

Note 2—Scaling temperature in low-sulfur atmosphere.

Note 3—Scaling temperature in high sulfur oxidizing atmosphere.

Note 4—Scaling temperature in high sulfur reducing atmosphere.

Note 5—Not recommended primarily to resist ammonia attack, but may be used where resistance to ammonia in low concentrations is an incidental requirement.

WESTINGHOUSE RECOMMENDATIONS

A & B—PROBABLY safe to use

C—Use only with CAUTION

D—Use should be avoided unless protected or unless appreciable corrosion can be tolerated, or provided for.

E—Use should be AVOIDED

Provisional Corrosion Ratings* of Commercial Alloys of Iron, Nickel and Chromium in Sea Water of Table II

MATERIAL	AISI Type Number	Typical W.E. & M. Co. (P.D. Spec.)	Provisional Ratings Sea Water*
Low Carbon Steel	....	1555, 2784	D+
Nickel Chrome	A-3135	....	D+
Chrome Molybdenum	A-4140	7940	D+
Copper Bearing Steel	....	4225	D+
4-6% Cr Steel	502	6396	D
12-14% Cr Steel	420	8213	C—to E Note 1
12-14% Cr 0.60% Mo	416	5161	C— to E Note 1
16-18% Cr	430	5284	C— to E Note 1
23-30% Cr	446	6770	C to E Note 1
7% Ni-17% Cr	301	7670	C to E Note 1
	302	4562	
8% Ni-18% Cr	303	6478	C to E
	304	5872	Note 1
8% Ni-18% Cr-1% Cb	347	7968	C to E Note 1
8% Ni-18% Cr-0.5% Ti	321	....	C to E Note 1
14% Ni-23% Cr	309	5758	C+ to E Note 1
12% Ni-18% Cr-3% Mo	316	8685	C+ Note 1
20% Ni-25% Cr	310	....	C Note 1
Nickel	....	1921	C— A Note 2
30% Ni-70% Cu	....	....	A Note 2
Monel	....	2718	C—
80% Ni-20% Cr	....	3012	
Inconel-80% Ni, 7% Fe-13% Cr	....	8153	C—

LEGEND, TABLE II (SEA WATER)

A—Practically complete resistance, or the alloy is the best of materials within its class.

B—Good resistance, as proven by being in common use. May replace materials given A rating to secure some other advantage.

C—Adequate resistance under favorable conditions which should be investigated beforehand.

D—Sufficient resistance if adequate precautions are taken to reduce effect of corrosive conditions, as by coatings, cathodic protection, re-design, etc., or where appearance is not important and appreciable corrosion may be provided for, or tolerated.

E—Poor resistance—use only if no better material is available.

*Corrosion ratings for metals in contact with salt water are subject to wide variations, depending upon geographical location, flow and cyclic heating. Ratings given for sea water applications shall be considered as a supplement to, rather than a replacement of, other means of arriving at a proper choice of material.

Note 1—With the stainless steels, the lower ratings refer to exposure to quiet, or slowly moving sea water, especially where marine organisms may become attached to induce pitting. The higher ratings refer to contact with sea water at high velocity, e.g. pump impellers for which the better stainless steels frequently give excellent service, especially in polluted harbor waters. The straight chromium stainless steels give their best performance when used at high velocity and in contact with ordinary steel, but should not be combined with bronzes.

Note 2—The 70:30 copper nickel alloy is preferred for condenser tubes, salt water piping and boat sheathing. Monel provides high strength, excellent resistance to erosion, and a favorable galvanic relationship to bronzes. It is the preferred material for valve trim, shafting, and for vital parts of assemblies which include bronze components.

TABLE III

Corrosion Ratings of Commercial Copper and Copper Alloys

(Data by courtesy of the American Brass Company)

MATERIAL	Typical W. E. & M. Co. Material (P. D. Spec.)	GENERAL OUTDOOR AIR			SPECIFIC INDUSTRIAL ATMOSPHERES (WET)				
		Rural	Urban	Marine	Ammonia	Hydrogen Sulfide	Hydrogen Chloride	Sulfur Dioxide	Chlorine
COPPERS									
Copper, Tough Pitch	2007	A	A—	A	E	C	C	B	C
Copper, Phosphorized	5536	A	A—	A	E	C	C	B	C
Copper, Oxygen Free	2003-3	A	A—	A	E	C	C	B	C
Cupaloy	7550	A	A—	A	E	C	C	B	C
Cadmium Copper	4623	A	A—	A	E	C	C	B	C
Beryllium Copper	7534	A	A—	A	E	C	C	B	C
Selenium Copper	8540	A	A—	A	E	C	C	B	C
BRASSES									
Gilding Metal (95-5)	....	A	A—	A	E	C	C	B	C
Commercial Bronze (90-10)	8 12	A	A—	A	E	C	C	B	C
Red Brass (85-15)	7292-7790	A	A—	A	E	C	C	B	C
Low Brass (80-20)	7410	A	B+	A—	E	C+	E	C	E
High Brass (70-30)	8010	A	B	B+	E	B—	E	C—	E
High Brass (68-32)	2677	A	B	B+	E	B—	E	E	E
High Brass (66-34)	2411-2676	A	B—	B+	E	B—	E	E	E
Muntz Metal (60-40)	6811	A	B—	B+	E	B—	E	E	E
LEADED BRASSES									
Leaded Commercial Bronze 88-10-2%	....	A	A—	A	E	C	C	B	C
Hardware Bronze	7790	A	A—	A	E	C	C	B	C
Low-Leaded Tube Brass	2430	A	B—	B+	E	B—	E	E	E
Low-Leaded Brass	8182	A	B—	B+	E	B—	E	E	E
Medium-Leaded Brass	7785	A	B—	B+	E	B—	E	E	E
High-Leaded Brass	....	A	B—	B+	E	B—	E	E	E
Extra-High-Leaded Brass	1523-2724	A	B—	B+	E	B—	E	E	E
Leaded Muntz Metal	6377-2840	A	B—	B+	E	B	E	E	E
Forging Brass	4097	A	B—	B+	E	B	E	E	E
Architectural Bronze	3134	A	B—	B+	E	B	E	E	E
BRONZES									
Phosphor Bronze 1¼%	7342-7413	A	A—	A	E	C	C	B	C
Phosphor Bronze 5%	2383-2709	A	A—	A	E	C	C	B	C
Phosphor Bronze 6%	....	A	A—	A	E	C	C	B	C
Phosphor Bronze 8%	4118	A	A—	A	E	C	C+	B	C
Phosphor Bronze 10%	3503-4121	A	A—	A	E	C	C+	B	C
Hard Bronze (88-4-4-4)	6014	A	A—	A	E	C	C	B	C
SPECIAL BRASSES									
Admiralty	7634	A	B	B+	E	B—	E	C	E
Naval Brass	2824	A	B	B+	E	B	E	E	E
Leaded Naval Brass (60-38-1.5)	....	A	B	B+	E	B	E	E	E
Manganese Bronze	5184	A	B	B+	E	B	E	E	E
Aluminum Brass	6052	A	B	B+	E	B—	E	C	E
CUPRO-NICKELS									
Cupro-Nickel (70% Cu-30% Ni)	....	A	A—	A	E	C—	C+	B	C+
Nickel Silver, Alloy A (18% Ni-65% Cu-17% Zn)	8130	A	A—	A	E	C—	C+	B	C+
*Nickel Silver (30% Ni-47% Cu-23% Zn)	1498	A	B	A	E	C	E	C	E
*Nickel Silver, Alloy B (18% ni-55% Cu-27% Zn)	3296	A	B	A	E	C	E	C	E
SPECIAL BRONZES									
Silicon Bronze	7610	A	A—	A	E	C	C+	B	C+
Silicon Bronze	8308	A	A—	A	E	C	C+	B	C+
Silicon Bronze	4448	A	A—	A	E	C	C+	B	C+
Silicon Bronze	4788	A	A—	A	E	C	C+	B	C+
5% Aluminum Bronze	....	A	A—	A	E	C+	C	B	C
Al, Ni-Fe-Cu	6799	A	A—	A	E	C+	C	B	C

LEGEND, TABLE III

A—Practically complete resistance, or the alloy is the best of materials within its class.

B—Good resistance, as proven by being in common use. May replace materials given A rating to secure some other advantage.

C—Adequate resistance under favorable conditions which should be investigated beforehand.

D—Sufficient resistance if adequate precautions are taken to reduce effect of corrosive conditions, as by coatings, cathodic protection, re-design, etc., or where appearance is not important and appreciable corrosion may be provided for, or tolerated.

E—Poor resistance—use only if no better material is available.

Plus and minus signs are used to permit a better differentiation between the corrosion-resistant qualities.

*Used principally for electrical resistance properties.

WESTINGHOUSE RECOMMENDATIONS

A & B—PROBABLY safe to use.

C—Use only with CAUTION.

D—Use should be avoided unless protected or unless appreciable corrosion can be tolerated, or provided for.

E—Use should be AVOIDED.

LEGEND, TABLE III (Sea Water)

A—Practically complete resistance, or the alloy is the best of materials within its class.

B—Good resistance, as proven by being in common use. May replace materials given A rating to secure some other advantage.

C—Adequate resistance under favorable conditions which should be investigated beforehand.

D—Sufficient resistance if adequate precautions are taken to reduce effect of corrosive conditions, as by coatings, cathodic protection, re-design, etc., or where appearance is not important and appreciable corrosion may be provided for, or tolerated.

E—Poor resistance—use only if no better material is available.

Plus and minus signs are used to permit a better differentiation between the corrosion-resistant qualities.

WESTINGHOUSE RECOMMENDATIONS

A & B—PROBABLY safe to use.

C—Use only with CAUTION.

D—Use should be avoided unless protected or unless appreciable corrosion can be tolerated, or provided for.

E—Use should be AVOIDED.

*Corrosion ratings for metals in contact with salt water are subject to wide variations, depending upon geographical location, flow and cyclic heating. Ratings given for sea water applications shall be considered as a supplement to, rather than a replacement of, other means of arriving at a proper choice of material.

Provisional Corrosion Ratings* of Commercial Copper and Copper Alloys in Sea Water of Table III

MATERIAL	Typical W. E. & M. Co. Material (P.D. Spec.)	Provisional Ratings* Sea Water
COPPERS		
Copper, Tough Pitch	2007	B—
Copper, Phosphorized	5536	B—
Copper, Oxygen Free	2003-3	B—
Cupaloy	7550	B—
Cadmium Copper	4623	B—
Beryllium Copper	7534	B—
Selenium Copper	8540	B—
BRASSES		
Gilding Metal (95-5)	....	B—
Commercial Bronze (90-10)	8012	B—
Red Brass (85-15)	7292-7790	B—
Low Brass (80-20)	7410	C+
High Brass (70-30)	8010	C
High Brass (68-32)	2677	C
High Brass (66-34)	2411-2676	C—
Muntz Metal (60-40)	6811	C—
LEADED BRASSES		
Leaded Commercial Bronze 88-10-2%	....	B—
Hardware Bronze	7790	B—
Low-Leaded Tube Brass	2430	C—
Low-Leaded Brass	8182	C—
Medium-Leaded Brass	7785	C—
High-Leaded Brass	....	C—
Extra-High-Leaded Brass	1523-2724	C—
Leaded Muntz Metal	6377-2840	C—
Forging Brass	4907	C—
Architectural Bronze	3134	C—
BRONZES		
Phosphor Bronze 1¼%	7342-7413	B—
Phosphor Bronze 5%	2383-2769	B—
Phosphor Bronze 6%	....	B—
Phosphor Bronze 8%	4118	B
Phosphor Bronze 10%	3503-4121	B+
Hard Bronze (88-4-4-4)	6014	B
SPECIAL BRASSES		
Admiralty	7634	B+
Naval Brass	2824	B—
Leaded Naval Brass (62-38-1.5%)	....	B—
Manganese Bronze	5184	B—
Aluminum Brass	6052	A—
CUPRO-NICKELS		
Cupro-Nickels (70% Cu-30% Ni)	....	A
Nickel Silver, Alloy A (18% Ni-55% Cu-17% Zn)	8130	B+
*Nickel Silver (30% Ni-47% Cu-23% Zn)	1498	B
*Nickel Silver, Alloy B (18% Ni-55% Cu-27% Zn)	3296	B
SPECIAL BRONZES		
Silicon Bronze	7610	B—
Silicon Bronze	8308	B—
Silicon Bronze	4448	B—
Silicon Bronze	4788	B—
5% Aluminum Bronze	....	B+
Al.-Ni-Fe-Cu	6799	B+

Discussion

By R. E. McNulty

The Dow Chemical Company, Midland, Michigan

Studies of the corrosion performance of magnesium alloys in a wide variety of testing and service conditions by the metallurgical laboratories of The Dow Chemical Company, indicate that certain amendments to the very informative tables may be in order.

Before demonstrating the data which impels these modifications, we should like to call attention to certain typographical errors in the original Table I. First, the 1.5 percent Mn alloy (Dowmetal M) should have the Alcoa designation AM3S rather than AM35. The Mg-3%Al-1%Zn-0.2%Mn alloys called AM52S has, as shown below, 1 percent Zn rather than 10 percent. Further, the Dow company produces this alloy only in the —1, or controlled purity designation. The corresponding Alcoa designation is AMC52S. It is for this composition with the detrimental impurities iron, nickel and copper controlled below their "Tolerance Limits" (1) that the Dow data applies.

We should alter Table I to read as shown at the bottom of this page.

The changes suggested are based upon the comprehensive paper by Loose (2) summarizing the "Corrosion and Protection of Magnesium." Figures 21 and 22 of his paper show that cast and extruded magnesium alloys suffer less severe property losses than plain carbon steel in the Midland industrial exposure, and are quite comparable with the aluminum alloys.

Comparison of figures 24 through 26 of the same report shows that present commercial magnesium alloys are very much superior to plain carbon steels in the marine environment, 80 feet from the ocean. For example, the poorest present commercial magnesium sheet alloy shown loses about 20 percent of its tensile strength after four years exposure (bare) in this environment, while the plain carbon-steel sheet loses almost 100 percent of its strength in six months.

Present commercial controlled purity sheet magnesium alloys lost only six percent of their tensile properties in four years exposure. Further, comparing rounds, the plain carbon steel lost 90 percent of its properties in four years, while the magnesium alloys lost only 5 percent, thus comparing favorably with 24ST aluminum on a property-loss basis under such conditions.

Accordingly, we should suggest that the classification "D" used in the tables was not intended to include such magnitudes of change in tensile strengths, and that the modification we have suggested is a more precise statement.

References

1. J. D. Hanawalt, C. E. Nelson and J. A. Peloubet, Metals Tech, October, 1941.
2. W. S. Loose, Magnesium, Chapt. V, American Society for Metals, Cleveland, Ohio, 1946.

MATERIAL	DESIGNATION		EXPOSURE		
	Alcoa	Dow	Rural	Urban	Marine
98%Mg.—1.5%Mn	AM3S	M	B	B	C
95.8%Mg—3%Al—1.0%Zn—0.2%Mn	AM52S	FS-1	B	B	B
88.8%Mg—9%Al—2%Zn—0.2%Mn	AM260	C	B	B	C
93.8%Mg—6%Al—3%Zn—0.2%Mn	AM265	H	B	B	C

Resistance of Some Nickel-Containing Alloys to West Texas Crudes

By B. B. Morton

Development & Research Division, The International Nickel Company, Inc., New York, N. Y.

THE name West Texas, in connection with petroleum, readily leads to thoughts of corrosion of both producing and refining equipment. While a number of wells and crudes of West Texas amply maintain the reputation for corrosiveness, associated with the locality, it must be recognized that the intensity of corrosion ranges widely in the area. Wells are found in West Texas that vary from those considered "slightly corrosive" through increasing degrees of corrosiveness to ones possessing a vigorousness of corrosion possibly unequalled in any other field. The corrosive agent in West Texas oil is primarily sulphur in the form of hydrogen sulphide and organic sulphides that can be changed into hydrogen sulphide during refining operations.

Experience has shown that nickel and Monel (approximately 2/3 nickel, 1/3 copper) are highly resistant to the corrosion experienced by steels in the production of West Texas crudes. In refineries, chromium is the element most resistant to the attack at elevated temperatures by sulphur from West Texas and other crudes. The nickel containing stainless steels (high chromium steels) are the most resistant commercially available materials for use at temperatures above about 500° F. in refining West Texas crudes. Below this temperature level, Monel and nickel enter the picture as the most resistant materials, possessing other desirable properties. The reason for this is, as has been pointed out before (1), at temperatures below about 500° F. and approaching atmospheric, the presence of water occurs and the character of the corrosion changes from "dry" attack to electrolytic forms.

The discussion of equipment in the following is intended to amplify and illustrate the above statements.

Production Equipment

Production equipment in West Texas is exposed to sulphur-containing crude oil, hydrogen sulphide and to gas saturated brines of varying degrees of corrosiveness. Apparently the corrosiveness of a well in this locality varies from season to season and from year to year. Even moderately corrosive wells are often equipped against the time when they will become more corrosive.

Sucker Rods

Sucker rods represent an important item of expense in pumping petroleum in corrosive areas. Since the rods are used to transmit the pumping power at the surface to a reciprocating pump at the well bottom, the load on the rods sets up reversing stresses that tend to pro-

duce fatigue failure. Hence the endurance limit of the material is the basis for design of a string of rods. The endurance limit of sucker rods, as of any parts subjected to reversals of loads, has no constant value. The best value is obtained from a polished specimen tested in dry air. The endurance limit of many steels, determined under ideal conditions, is approximately one-half the ultimate strength. Roughness of surface, scratches and corrosion of the surface all tend to lower the endurance limit.

The reaction of hydrogen sulphide upon steel appears especially to adversely affect the endurance limit of most sucker rod steels. The action is apparently associated with the presence of hydrogen in the steel, which renders it more notch sensitive. The hydrogen is released by the reaction of hydrogen sulphide upon steel.

Dr. B. B. Wescott and C. Normal Bowers, of the Gulf Research & Development Co., were among the first to describe the effect of corrosives in petroleum wells upon the endurance limit of steels used for sucker rods. Their now classical paper on "Economical Selection of Sucker Rod Materials" (2), by outlining the problem and the course of the destructive effects, has resulted in the use of fatigue testing as the basis for selection of materials for different types of rods for use in different pumping jobs. This paper can also be accredited with establishing and extending the use of nickel-containing steels and irons as sucker rod materials.

As a result of the studies such as were reported by Wescott et al., and others, by practical experience, nickel alloy steels of increasing nickel contents are used to resist corrosive pumping conditions. Such steels as SAE 4615, or 4620; SAE 4820; SAE 2315, and steels containing 3-4 percent nickel, with and without other elements, notably copper (Yoloy), chromium and molybdenum are widely used. The trend of increased nickel contents in sucker rod materials to maintain as high as possible the "air" endurance limit is widely noted. A newcomer in the form of an 8-10 percent nickel alloy has made its appearance. The high mechanical properties obtained from normalized and drawn rods of an 8½ percent nickel variety, containing 0.10 percent carbon maximum, indicate this alloy has many properties that render it worthy of consideration for sucker rod service. The effects of the higher nickel content upon the endurance limit under corrosive conditions remains to be determined before a final assessment of the value of this newly developed steel can be made for sucker rod use. The high endurance limit (air) suggests it for heavy pumping conditions in the absence of marked corrosion.

While the nickel content of current sucker rod steels appear to provide an adequate and economical rod for use in corrosive service, there are some locations where the corro-

TABLE I

Some Mechanical Values Obtained from a 8½ % Nickel Steel Proposed for Sucker Rod Service

Ultimate Tensile Strength, psi	115,000
Yield Strength, psi	104,000
Elongation in 2 inches, percent	26
Reduction in Area, percent	64
Endurance Limit (Air), psi	72,000
Ratio, Endurance Limit/Ultimate Tensile Strength, percent	62

NOTE: Double normalized and drawn at 1050° F.

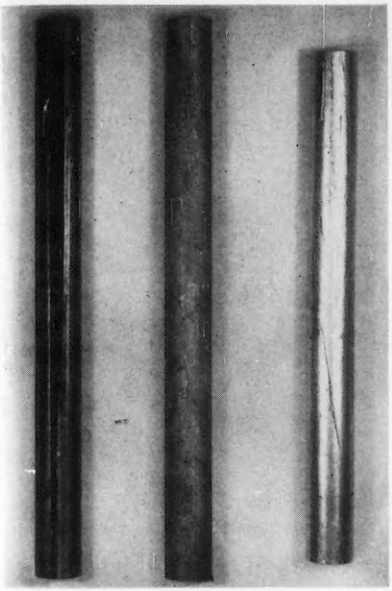


Figure 1—Nickel-plated sucker rods after service in Smackover Field (Ark.) and West Texas. (Center rod after five years service in West Texas.)

sion rate is so high, even for these rods, that thoughts have turned to protective surfaces such as nickel plating.

That corrosion of steel can be effectively retarded by nickel was demonstrated by tests involving nickel-plated sucker rods. Rods plated with about 0.006 inch of nickel have been reported in very good condition after six and eight years of service. In one case, only part of the string was of plated rods and the other part was of a high nickel (3.5%) alloy steel rod. The unplated rods were removed after about three years, no longer fit for service. The plated rods were in good condition after five years (Figure 1). A very long life from nickel-plated rods can be assumed if the rods can be protected from striking the tube walls. If the rods strike the walls, the nickel will be worn through.

Whether nickel-plated rods or Monel rods, to be discussed later, cause accelerated corrosion of steel parts appears to be a moot question. Some nickel-plated rods exposed to the corrosive brines of an Arkansas field struck the tubing wall and wore through the plating (3). The exposed steel showed none of the effects that would have been expected if galvanic corrosion had been taking place. Reports have been made of galvanic corrosion as the result of using a nickel-plated string. Corrosion was stated to have been accelerated in the case of the tubing. The writer is of the opinion that galvanic corrosion is greatly suppressed, and often absent, in oil wells due to the absence of oxygen. Also, the presence of iron sulphide on the surface of steel and of nickel sulphide on the rods may further limit the galvanic effects by possibly blocking metal displacement in the case of wells containing hydrogen sulphide.

While the good behavior of nickel-plated rods indicated excellent resistance of nickel to oil well corrosion, the destruction of some of the rods by contact with the walls led to the use of a solid material in the form of K-Monel (a heat treatable form of Monel containing aluminum) for some trial strings. The mechanical properties of this alloy, hot rolled and aged, are given in Table II.

A string of ¾-inch K-Monel sucker rods was installed in West

Texas about four and a half years ago. Upon recent inspection, the rods appeared to be in excellent condition (Figure 2). A report, dated 7 December, 1945, on the behavior of the rods from Mr. E. G. Rodman of The Rodman Supply Co., Odessa, Texas, the present owner, states in substance: "The string of ¾-inch K-Monel rods has been in continuous service for 1,471 days. The rods were installed in 1941 with a 2¼-inch barrel on 2½-inch tubing. In July 1944, the barrel was changed to 2¾ inches on 3-inch tubing. The additional load has apparently caused no distress to the rods.

Two strings of ⅞-inch K-Monel rods were subsequently installed in the Howard Glasscock Field during July 1945, in a location where alloy steel rods suffered excessive breakage (reported to average two breaks per week after an initial period of time) and apparently are giving satisfactory service.

TABLE II

Mechanical Properties of K-Monel Sucker Rods (Hot Rolled and Aged Material)

Ultimate Tensile Strength, psi	152,000
Yield Strength, psi	103,000
Elongation, in 8 inches, percent	25.8
Reduction in Area, percent	43.5

(Courtesy of W. C. Norris, Mfgrs., Tulsa, Okla.)

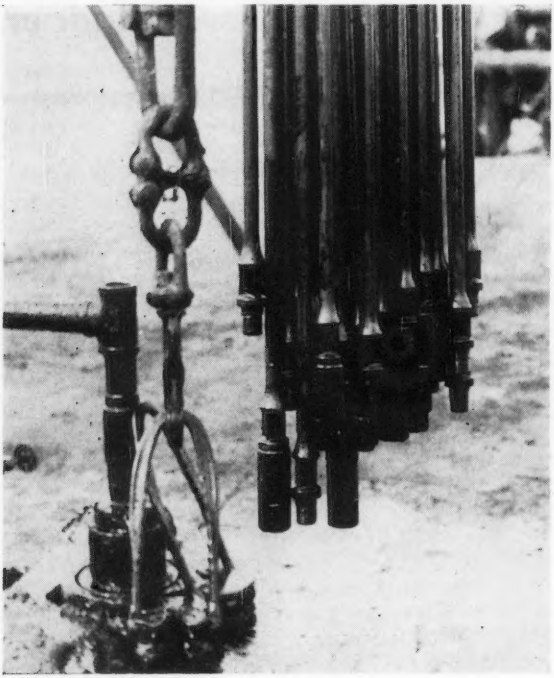


Figure 2—K-Monel sucker rods and couplings after about four years service in West Texas.

Polished rods are an important member of the sucker rod string. These rods are introduced into the well, then withdrawn into the air. At the same time, the packing rubs the protective film from the surface, exposing metal to further attack.

Monel has distinguished itself as a polished-rod material when used in the solid rod form. A rod of steel jacketed by drawing a Monel tube over it gave rather poor service where any bending of the rod occurred. High residual stresses in the jacket may have also accounted for the fatigue failures that occurred in the case of these jacketed rods.

Monel polished rods have given ex-

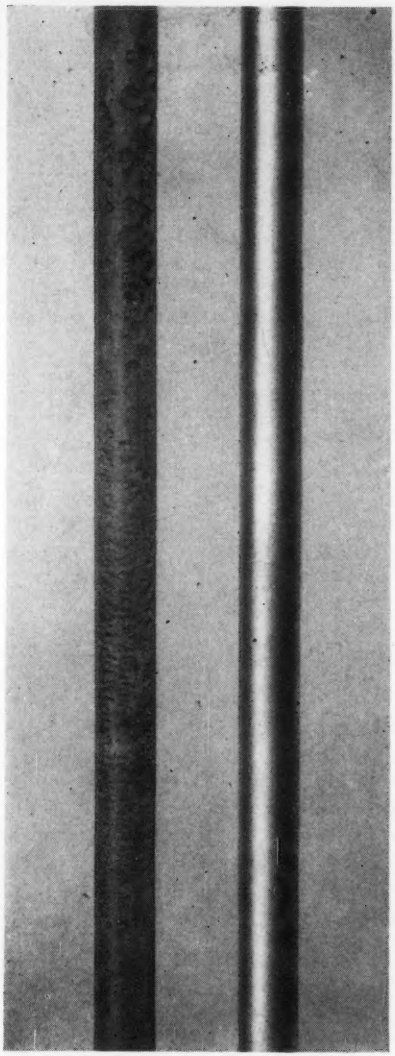


Figure 3—Polished rods from same location. Number 1, steel polished rod after three months service. Number 2, Monel polished rod after about five years service.

cellent service in such corrosive fields as West Texas and West Kansas (Figure 3). A rod made of this alloy from West Kansas was returned after about 11 years of service. An interesting feature of Monel polished rods is that pitting, if it occurs, does not seem to be of a nature to destroy packing. A number of Monel polished rods giving long service were reported to have suffered superficial pitting early in their service life.

The high mechanical properties of hot rolled and aged K-Monel suggests it for use in heavy pumping fields. At the present time, the area of the Monel polished rods in service appears to provide a stress of an order within the endurance limit of this metal, i.e., about 30,000 psi (minimum). This value was reported from tests in brackish water, which may be assumed as representative of corrosive brine in well conditions.

Pumps and Pump Parts

The nickel-copper alloys (Table III) are widely used in oil well pumps for such parts as travelling tubes, rings, valve parts and liners. For applications involving abrasion, chromium plating is often applied over the Monel or nickel part. The corrosion resistance of the alloy aids in retaining the chromium plate in place.

A contrast between the resistance of steel and Monel is provided in Figure 4. There one can view the utter destruction of the steel part and the good condition of the Monel spring. As a result of such demonstrations, the entire parts of deep well pumps are increasingly made

TABLE III
Approximate Compositions

MATERIAL	Percent Nickel	Percent Copper	Percent Iron	Percent Chromium	Percent Aluminum	Percent Silicon	Percent Magnesium	Percent Carbon
Nickel	99.4*	0.1	0.15	....	....	0.05	0.2	0.1
Monel	67.	30.	1.4	....	....	0.1	1.	0.15
"H" Monel †	65.	29.5	1.5	....	....	3.	0.9	0.1
"S" Monel †	63.	30.	2.	....	....	4.	0.9	0.1
"K" Monel	66.	29.	0.9	....	2.75	0.25	0.4	0.15
Inconel	79.5	0.2	6.5	13.	....	0.25	0.25	0.08

* Including cobalt. † Available only in cast form.

from the different grades of nickel-copper alloys.

The high corrosion resistance of K-Monel to oil-well corrosives, the fair degree of hardness obtainable from this alloy and its non-magnetic quality, all have combined to further the use of the alloy as balls and drops, and also seats of valves in petroleum wells (Figure 5).

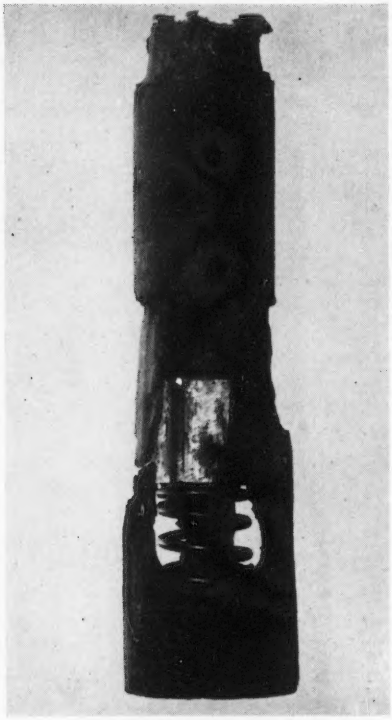


Figure 4—Standing Valve Puller.

The maximum hardness obtainable from this alloy, about 350 Brinell, is not of a sufficiently high order to permit the use of valves of this metal at depths greater than about 4,000 feet. However, valve equipment is most exposed to corrosion in fairly shallow wells, as some of those in West Texas and West Kansas. Here this alloy does an excellent job.

Recent experiments with the composition of some high nickel materials gives promise that a very hard material is about to be evolved that will possess many of the desirable features of K-Monel for valve equipment. The higher hardness of this new alloy should permit its use at great depths. Hardness values approaching about 600 Brinell are anticipated.

Wires

An increasing need is felt for strong and corrosion resistant wires. These are used to lower instruments into the well; to operate gas lift equipment, and for other uses. The high strength of piano wire first dictated its use. The corrosives encountered in sulphur-containing wells caused rapid destruction of this unalloyed steel wire.

Corrosion resistant alloys are now

generally used for high-strength wires, among these are 18/8; Type 316 stainless (18% chromium, 14% nickel, 3% molybdenum); K-Monel and Z Nickel. For continuous service in a well, K-Monel is possibly the most satisfactory with Type 316 as a contender. K-Monel wire is usually specified to have 150,000 psi (minimum) tensile strength, with sufficient ductility to permit its being wrapped on its own diameter.

Gas-Lift Equipment

The raising of oil from wells by means of gas lifting is quite popular in many locations. The equipment must of necessity be resistant to sulphur (hydrogen sulphide) and brine corrosives. Abrasion and "wire drawing" are also factors tending to destroy this equipment.

A large amount of ingenuity has gone into the manufacture of gas-lift equipment (Figure 6). The bellows diaphragm is an important part of some of this equipment. It regulates the pressure at which gas is introduced into the tubing to lift the oil.

In Figure 7, the excellent resistance of the Monel bands, in contrast to the corroded condition of the steel parts, led to the use of Monel for all parts. The suspicion that galvanic conditions may have been responsible for protection of the Monel rings has been dispelled by the subsequent behavior of Monel parts against the corrosion here noted.

Monel and K-Monel are standard material for the important parts of much of the gas-lift equipment. The selection is based on the observed good corrosion resistance of these alloys to hydrogen sulphide and corrosive brines. The higher hardness of the K-Monel has directed its use for seats and seating parts. Monel bellows apparently have been the most successful of any so far tried.

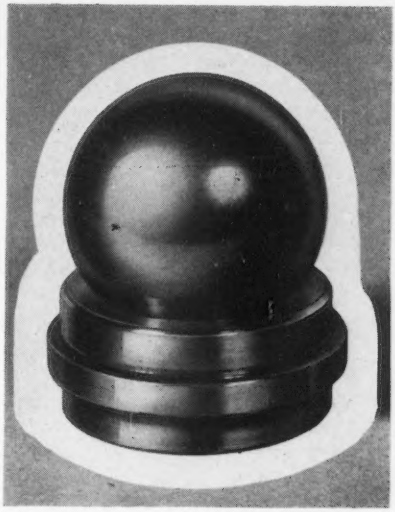


Figure 5—K-Monel ball and seat valve.

The writer recently surveyed the manufacturers of gas-lift equipment, to find if galvanic corrosion affects the immediate tubing where the gas-lift units are attached, and received the remarkable reply that this section of tubing is apparently less corroded than other parts. And in fact, the Monel was considered to give a form of protection, so that in one case "pads had been welded to the tubing" in order to gain this protection. The replies are still being pondered. The fact remains that the section of tubing was not especially attacked.

It is during refining of some crudes from West Texas that the

true virulence of the corrosive attack from these crudes and fractions from the crudes can be noted. Stories from refineries and units handling some of the West Texas crudes border almost on the fantastic when recounting the destruction of carbon-steel parts that takes place during distillation and cracking operations.

The corrosion of refining equipment by West Texas and other similar crudes has been the subject of wide study and some helpful reports by L. R. Gray (4), J. A. Jamison (3), and by many other writers, have been prepared to guide technologists.

Linings of Vessels

Sulphur is the cause of vigorous corrosion of much refinery equipment. At temperatures above about 500° F., chromium-containing alloys must be used. Below this temperature level, such nonferrous alloys as Monel; 70-30 copper-nickel; Admiralty; etc., are required to give satisfactory corrosion resistance.

Some of the most satisfactory vessels to operate at temperatures well above 500° F. are formed from steel previously clad with stainless prior to forming. Some such vessels have been formed from "Pluramelt" clad steel, and serve as part of the equipment in a fluid catalyst cracking unit. Type 347 (18/8 stainless stabilized with columbium) is reported to be one of the stainless steels used as the cladding in this service (Figure 8). Nickel-containing, stainless-clad steels have found wide use combating sulphur corrosion. A large bubble tower clad with 18/8 over the high temperature region and Monel in the top section by the "Smith lining" method is shown in Figure 9.

The use of strip lining has been widely applied to existing vessels, and many vessels operating above 500° F. are lined with stainless of the 18/8 type and also the 12-14 percent chromium variety. The weld rod used in applying the stainless linings is 18/8, or better (25% chromium, 20% nickel). This latter rod seems to be preferred for position welding.

Where a temperature gradient in a vessel carries the temperature below 500° F., as in the top

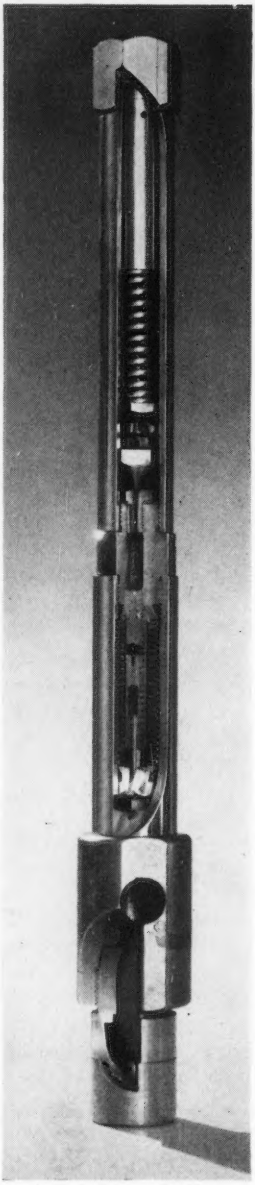


Figure 6—Gas lift valve.

section of a bubble tower, the lining material is changed from say 18/8 to Monel, since the character of the corrosion differs in that part due to the presence of water. Caps and trays are also varied in composition of material, as the character of the corrosion changes. Usually stainless steel is used to a point where the temperature drops below about 500° F., then Monel is used.

Condenser shells are subject tc corrosive attack. Monel is widely used to line these parts. In some cases the high mechanical strength of the Monel (about 75,000 p.s.i. ultimate strength) is utilized by making the shell of this alloy. Monel is also used to line or to provide the lines from the tops of towers to condensers.

Caustic is often employed in connection with the refining of high sulphur crudes. In caustic regenerators and vessels in which caustic is heated for the purpose of recovering products from it, Monel and nickel are used as liners, and also as heater tubes and for conveying lines. Nickel is more resistant to high caustic concentrations, 50° Be and above, than is Monel. Monel appears better suited for use in connection with weaker concentrations and for general refinery handling of caustic (under 50° Be).

Exchanger and Condenser Tubes

Exchanger tubes offer quite a problem in service where high sulphur content gases sweep over them. Tubes made of 18/8 have a very high order of resistance to the destructive elements of corrosion and abrasion to which exchanger tubes are exposed.

Tests of Inconel tubes (approximately 80% nickel — 13% chromium) have shown this material highly resistant to sulphur attack. This alloy is especially resistant to attack by naphthenic acids, to which 18/8 is not satisfactorily resistant. Type 316 stainless is apparently quite resistant to both sulphur attack and naphthenic acid attack or to attack

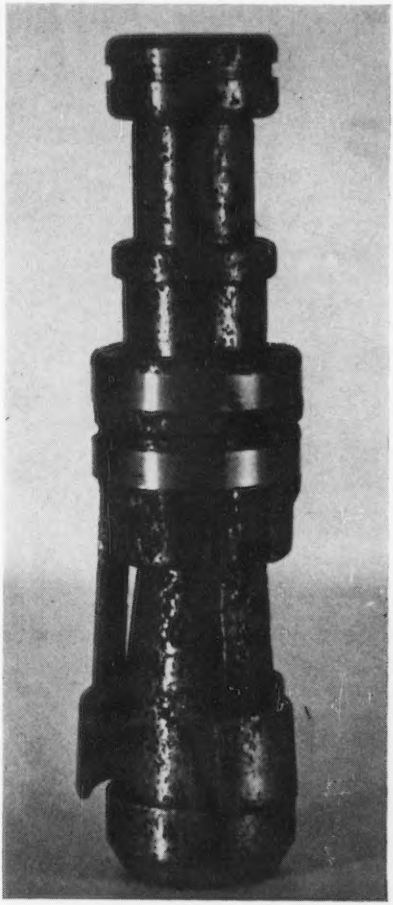


Figure 7—Otis removable side door choke. Monel bands, steel body.

by other organic acids.

Type 316 stainless (18-13-3) is becoming one of the most important of the austenitic stainless steels used in refineries. Its resistance to organic acids and reagents as acetic acid, etc., also to sulphurous acid and to mixtures of various mineral and organic acids accounts for its popularity and extended uses.

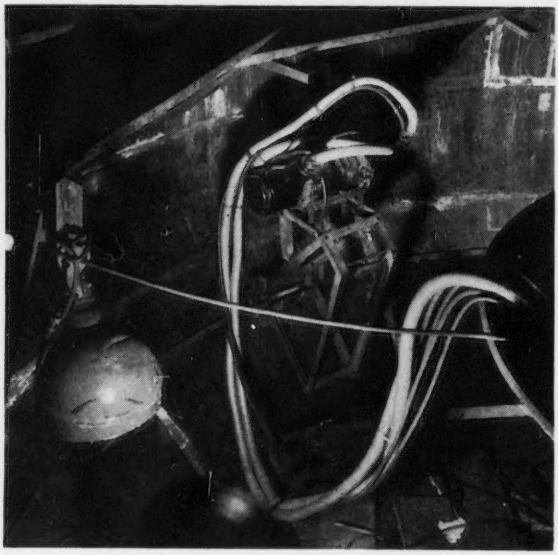


Figure 8—Stainless Steel 'Pluramelt' lining. Reactor of catalyst cracking unit.

Condensor tubes made of 70-30 copper-nickel are rapidly expanding their use in refineries to replace Admiralty in services in which this alloy suffers dezincification or impingement attack. The increased use of 70-30 is particularly noticeable where salt water is used as the coolant.

Monel tubes are used where especially corrosive conditions involving caustic, hydrochloric acid, and other corrosive reagents are encountered.

A large tonnage of pressed alloy caps and lightweight trays, made from strip or sheet, is in service in refineries to resist corrosive conditions (Figure 10). Caps and trays made from 18/8 find wide use in bubble towers of refineries handling West Texas crude or products. The cooler, top, trays and caps are often of Monel due to mineral acids in the reflux.

Pumps are important pieces of refinery equipment. A vast number and variety of pumps are to be found in a large refinery. Hot oil pumps, especially those handling sour fractions, are special cases since they must operate at temperatures often high enough to be optically noted under favorable conditions. High chromium stainless steels and Stellite enter into parts of these pumps as well as the well-known 4-6 percent chromium alloy steel.

That a wide variety of alloys is used in pumps handling products from West Texas crudes is indicated in the report by L. R. Gray (4). The change in metallurgy with change in temperature is emphasized in Table 4 of his article, which deals with pump parts.

Reflux pumps and many product handling pumps must be equipped to resist the corrosion resulting from high sulphur containing fractions.

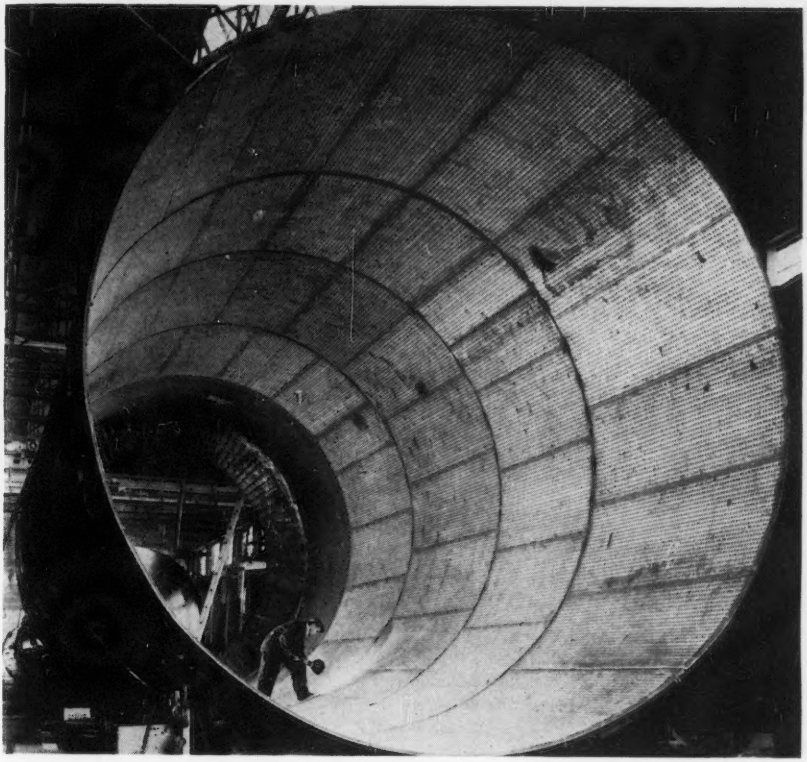


Figure 9—Smith-lined bubble tower, with 18-8 over bottom section, Monel top dome.

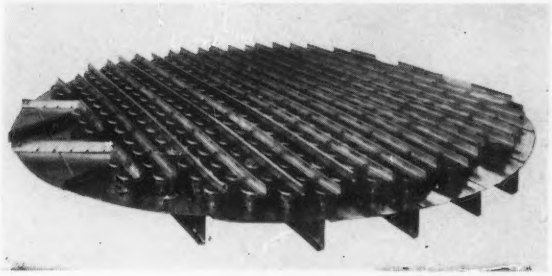


Figure 10—Corrosion resistant fabricated caps and trays.

Ni-Resist, a highly alloyed cast iron (approximately 15% nickel, 5% copper and 2% chromium) is extensively used for parts of many pumps. It will be found as liners, pistons, piston rings, impellers, casings and parts of valves of pumps handling corrosive reflux or distillates. The

good behavior of Ni-Resist in some refinery tests has been noted and reported by Pollock, et al. (6).

Where a high order of resistance to abrasion, or galling, as well as a high resistance to corrosion is required in connection with handling of products from high sulphur crudes, S-Monel is used and appears as such parts as sleeves, wear rings, liners and pistons. This form of Monel resists seizing when acting against itself, stainless or other materials of pump construction.

The high strength, corrosion resistance, and fair degree of hardness obtained from K-Monel has dictated its use as pump rods and shafts and, in some cases, as sleeves of product-handling pumps. Monel is used in valves of many of the pumps handling reflux or other products from high sulphur containing crudes.

Heating Coil Tubes

Tubes of 18/8 have shown the highest order of resistance to sulphur attack of any material so far used for this purpose. The tubes of 18/8 have been reported as giving compressors from 60,000 to 100,000 hours service when handling sour fractions. In the case of some tubes of 18/8, after 40-60,000 hours service handling high sulphur charge stock, there was no appreciable thinning due to sulphur attack.

Compressors are subject to corrosion by sour (sulphur containing) gases. Ni-Resist liners and valves of high nickel alloys appear to resist this attack well.

Monel screens have made a good showing on vents of storage tanks containing sour crudes and fractions. This alloy is also used as a trim for valves as well as stems and other parts used in handling these products.

A brief survey of the uses of nickel containing alloys to resist the corrosion from some high sulphur West Texas crudes and products has been made. It is pointed out that the resistance of Monel and nickel to the corrosives encountered in producing West Texas crudes is of such a high order that nearly complete immunity to attack upon sucker rods, deep well pumps and other equipment can be expected by a proper application and use of high nickel containing alloys.

The widely differing nature of corrosion occurring in refineries is again referred to, and the appropriate alloys are suggested. For the temperature region above about 500° F., the chromium-nickel stainless steels are indicated, and below this temperature level, non-ferrous alloys are required, such as Monel, 70-30 copper-nickel alloys, Ni-Resist and other alloyed cast irons where high resistance is sought to the corrosives released during refining some West Texas crudes.

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Condensate Well Corrosion

Progress Report of Committee on Condensate Well Corrosion

To Executive Committee, National Association of Corrosion Engineers

W. F. ROGERS
Chairman

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B. B. WESTCOTT
F. S. WEST
W. E. WINN
Y. D. YALE

Committee

To the Executive Committee, National Association of Corrosion Engineers:

Your committee submits a brief report as follows:

THE COMMITTEE ON CONDENSATE WELL CORROSION,
W. F. ROGERS, *Chairman*

THE Condensate Well Corrosion Committee was started in September 1944, with the appointment of the chairman by Mr. R. A. Brannon, president of the association. At the time the chairman was appointed, the Corrosion Research Project Committee of the Natural Gasoline Association had circulated the major condensate producers and received donations for research studies. A committee was obtained and after several conferences with the NGAA group, the function of conducting field tests of metals and alloys was allocated to the NACE group, with the full backing of the NGAA group.

The work of the Committee has since proceeded along this line. The committee is composed of 23 members representing twelve oil companies, four metal and alloy manufacturers, one consulting firm, and the Bartlesville, Oklahoma, branch of the Bureau of Mines.

At meetings of the Committee during 1945, it was decided that, before proceeding with a series of field tests of metals, the first procedure should be to protest variable designs of test spools. This was decided in order to obtain for the final test an apparatus for which the required design of specimen could be easily obtained, which would have a relatively high corrosion rate, permitting results to be obtained within a short time and which would permit the corrosion experienced to be independent of the specimen position on the test spool.

In accordance with these decisions, two types of test spools were designed and constructed by the committee at the expense of the companies making the design. Both these test spools were tested in the Cotton Valley, Louisiana, field on the well, Gray Account No. 2, Well No. 1. This is known to be a "corrosive well."

The rectangular specimens were

tested during the interval May 9, 1945, to September 10, 1945. The cylindrical specimens were tested during the interval December 23, 1945, to March 26, 1946. Unfortunately, this latter test spool was lost by the railroad company and was not delivered to the Gulf Research and Development Company, who in combination with the National Tube Company prepared this test, until October 1, 1946.

A meeting of the Committee was held on May 8, 1946, in Kansas City, Missouri, during the annual convention of the Association. At this meeting, Mr. V. V. Kendall presented a statistical survey of the test results obtained from the rectangular type specimens. He was able to show that this method of testing was satisfactory.

In view of the uncertainty as to when the cylindrical specimens would be delivered by the railroad and the fact that the rectangular specimen type test spool was found satisfactory, the committee decided to adopt the latter design and proceed with the field testing. The Metallurgical Committee at this time selected 32 metals and alloys to be tested; and assigned the collection of the specimens to individuals and companies best able to procure them.

Since that date, seven producing companies have offered to purchase containers and test a set of the specimens. These containers cost approximately $500 each. They are being made by a single manufacturer, selected through competitive bidding by the Test Container Design Committee. At the present time, orders have been placed for all seven of the containers, and they are being fabricated.

All alloy specimens are being collected, and a good many have been received. These specimens are being collected at the Gulf Research and Development Company laboratory at Harmarville, Pennsylvania, which will serve as a central laboratory for all cleaning, weighing and examination of the specimens both prior to and after the test. Collection of the specimens is slow, but it is hoped the tests can be set this year.

A joint meet of the NACE group was held with the NGAA Corrosion Project Research Committee at the regular quarterly meeting of the latter Committee held October 17, 1946, at Dallas, Texas. At this meeting, the Chairman outlined the present progress of the tests. It was decided by the Committee that the tests on the seven sets of specimens should be conducted for 90 days each. Test data on liquids and gases contacting the specimens during these 90 test days were discussed, but this matter was not handled to a conclusion. Another meeting of the Committee will probably be called prior to the first of the year.

The Chairman feels that the progress of this Committee's work has been slow, but has proceeded with firm background development. It is hoped the main work of the Committee can be accomplished by the spring of 1947.

The Chairman also realizes that during the early formative period of the Society, that the committee has had to act as an independent group. It is hoped that from this time on the National Association will play a more important role in the activities of this group.

Investigation of Electrolytic Corrosion of Steel in Concrete

Progress Report of Committee 2, Electrolysis

Electrical Section, Engineering Division, Association of American Railroads

A. E. ARCHAMBAULT, *Chairman,*
R. BEEUWKES
PAUL LEBENBAUM
ORRIS MCGINNIS
G. K. SHANDS
J. M. TRISSAL
H. P. WRIGHT, *Vice-Chairman,*
S. M. VIELE

Committee

To the Electrical Section, Engineering Division:

Your committee presents below its third progress report on the electrolytic corrosion of steel in concrete which was prepared by the research staff of the Engineering Division. This investigation, which was authorized in 1943, is being continued during the present year with an appropriation of $1000 granted by the Association of American Railroads for 1945.

THE COMMITTEE ON ELECTROLYSIS,
A. E. ARCHAMBAULT, *Chairman.*

The study of electrolysis of steel in concrete was assigned to the research staff of the Engineering Division of the Association of American Railroads in 1943. Random Ferguson, electrical engineer, has been in charge of the tests and of preparing the report, under the direction of G. M. Magee, research engineer. The work is being carried on under the general supervision of a special subcommittee of the Committee on Electrolysis of the Electrical Section. The personnel of this subcommittee is as follows:

A. E. Archambault, assistant engineer, New York Central Railroad, New York.

R. Beeuwkes, electrical engineer, Chicago, Milwaukee, St. Paul & Pacific Railroad, Seattle, Wash.

J. M. Trissal, superintendent of communication and electrical engineer, Illinois Central System, Chicago.

S. M. Viele, assistant engineer, electrical department, Pennsylvania Railroad, Philadelphia, Pa.

The program assigned, after a study of the available information, was as given below:

(a) Establishment of a special test to determine resistance to ground, amount of current flow, and corrosion of steel embedded in different thicknesses and kinds of concrete under controlled conditions in the field;

(b) Study of a catenary pedestal at Collinwood, Ohio, on the New York Central which in the past had shown an excessively large current flow;

(c) Test some abandoned catenary pedestals on the Illinois Central which could be broken up to observe the amount of corrosion on the concrete encased steel;

(d) Study of voltage and current flow through existing catenary pedestals on various railways.

The first progress report, pub-

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TABLE I

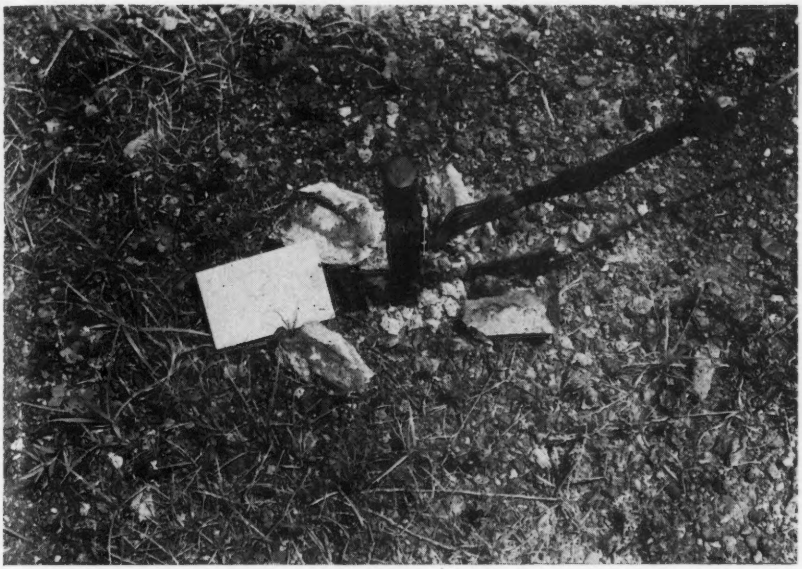
Special Field Test in I.C. R.R. near 23rd St., Chicago (25 Volts Direct Current Applied Except as Noted)

Specimen Number	DESCRIPTION	CURRENT FLOW IN AMPERES AS OF								
		June 9, 1944	June 19, 1944	July 14, 1944	Aug. 10, 1944	Sept. 11, 1944	Nov. 27, 1944	Jan. 18, 1945	April 23, 1945	July 16, 1945
1	3-in. Dia. Plain Concrete....	0.66	0.52	0.54	0.18	0.19	0.66	0.23	0.68*	0.14*
2	3-in. Dia. Plain Concrete....	.42	.37	.52	.78	.41	.26	.17	.22*	.12*
3	3-in. Dia. Plain Concrete....	.59	.46	.74	.72	.42	.22	.17	.25*	.16*
4	5-in. Dia. Plain Concrete....	.48	.39	.42	.30	.36	.89	.50	.51	.16*
5	5-in. Dia. Plain Concrete....	.48	.36	.36	.34	.32	.38	.19	.76*	.15*
6	5-in. Dia. Plain Concrete....	.49	.33	.40	.19	.19	.58	.23	.32	.14*
7	9-in. Dia. Plain Concrete....	.48	.28	.30	.26	.44	.60	.32	.46	.23*
8	9-in. Dia. Plain Concrete....	.66	.53	.44	.33	.30	.32	.12	.65*	.36*
9	9-in. Dia. Plain Concrete....	.50	.43	.31	.26	.20	.52	.41	.29*	.27*
10	13-in. Dia. Plain Concrete....	.47	.28	.26	.19	.19	.21	.09	.20	.11
11	13-in. Dia. Plain Concrete....	.52	.43	.34	.26	.28	.28	.18	.37*	.29*
12	13-in. Dia. Plain Concrete....	.44	.32	.22	.15	.13	.14	.06	.12	.10
13	25-in. Dia. Plain Concrete....	.42	.38	.29	.20	.19	.21	.12	.20	.15*
14	25-in. Dia. Plain Concrete....	.39	.43	.36	.36	.34	.27	.11	.21	.14*
15	25-in. Dia. Plain Concrete....	.63	.57	.48	.38	.36	.33	.11	.13*	.11*
16	6-in. Dia. Steel Encased.....	.80	.76	.62	.34	.40	.48	.07	.10	.11*
17	6-in. Dia. Steel Encased.....	.82	.74	.64	.32	.46	.44	.07	.10	.10*
18	6-in. Dia. Steel Encased.....	.87	.85	.61	.32	.51	.53	.07	.08	.10*
19	10-in. Dia. Steel Encased.....	.60	.60	.45	.28	.33	.34	.07	.12	.10*
20	10-in. Dia. Steel Encased.....	.62	.63	.51	.32	.35	.33	.06	.12	.10
21	10-in. Dia. Steel Encased.....	.74	.69	.60	.31	.42	.46	.07	.10	.10*
22	5-in. Dia. Asphalt Covered...	.09	.04	.07	.07	.10	.008	.002	.003	.004
23	5-in. Dia. Asphalt Covered...	.011	.008	.006	.004	.006	.005	.001	.002	.003
24	5-in. Dia. Asphalt Covered...	.064	.004	.002	.002	.003	.005	.001	.001	.003
25	13-in. Dia. Asphalt Covered...	.21	.23	.22	.21	.17	.045	.010	.032	.024
26	13-in. Dia. Asphalt Covered...	.28	.044	.032	.020	.028	.026	.005	.021	.017
27	13-in. Dia. Asphalt Covered...	.13	.012	.009	.007	.010	.014	.005	.007	.008
28	5-in. Dia. PCA Mixture.....	.41	.44	.42	.40	.42	.84	.13	.26*	.18*
29	5-in. Dia. PCA Mixture.....	.48	.34	.30	.32	.22	.38	.20	.43	.16*
30	5-in. Dia. PCA Mixture.....	.41	.28	.19	.18	.16	.50	.23	.22	.12*
32	13-in. Dia. PCA Mixture.....	.65	.48	.50	.25	.44	.37	.15	.68*	.26*
33	13-in. Dia. PCA Mixture.....	.50	.45	.38	.32	.31	.44	.21	.29	.35*
35	13-in. Dia. PCA Mixture.....	.53	.42	.34	.30	.31	.40	.19	.50	.44*
50	5-in. Dia. Celite Admixture..	.54	.46	.34	.25	.23	.34	.17	.41	.24*
43	13-in. Dia. Celite Admixture..	.48	.43	.38	.28	.28	.44	.22	.35*	.31*
44	5-in. Dia. Morene Admixture	.50	.30	.25	.12	.11	.19	.07	.21*	.17*
46	13-in. Dia. Morene Admixture	.45	.36	.22	.18	.17	.20	.06	.14*	.08*
48	5-in. Dia. Hyd. Lime Admix.	.40	.23	.18	.12	.12	.20	.06	.21*	.18*
45	13-in. Dia. Hyd. Lime Admix.	.56	.50	.37	.30	.31	.56	.23	.30*	.24*
34	5-in. Dia. AC Test (40 Volts)	....	....	....	....	.40	.53	....	.52	.37
31	13-in. Dia. AC Test (40 Volts)	....	....	....	....	.60	.54	....	.54	.46

* Specimen visibly cracked.

lished in the Reports of Committees of the Electrical Section, Engineering Division, Association of American Railroads, in 1943, outlined the progress and results on assignments (a) and (b) as of that date. The second progress report appeared in the Reports of Committees in 1944, and included a detailed description of the special field tests installed in connection with assignment (a), together with a detailed description of the different types of specimens and photographs showing the test arrangement and typical specimens as installed in the ground. The following report describes the additional progress made in connection with the special field tests in assignment (a) and also includes a description of the present condition of two catenary pedestals on the Illinois Central.

A detailed description of the test installation and of the specimens included in the tests is given on pages 10 and 11 of the second progress report and will not be reported here.



Figue 1—Specimen 2, 3-inch diameter, plain concrete, 1 cement, 3½ sand mix, with no covering. (July, 1945.)

After some preliminary readings and experimentation to get the proper source of current supply, a direct current potential of 25 volts was applied to all specimens (except those for the alternating current tests) and readings of current flow at each specimen were taken on June 9, 1944, and at various intervals of time thereafter. The results of these readings are given in Table I. As will be noted from this table, the amount of current flow at the various specimens was not markedly different except for the specimens with the asphalt waterproofing covering which showed a very low flow. There is also apparent a definite trend indicating an increasing resistance and decreasing amount of current flow for all of the specimens, generally, as the test progressed. This may be due to the specimens developing an increased resistance to current flow, as was found in the laboratory test, or to changes in the ground conditions, particularly with respect to the amount of moisture contained.

By July 1945 it was quite evident that most of the concrete specimens had suffered considerable damage as a result of the electrolytic action. The plain concrete specimens of small diameter had completely broken away from the steel electrodes above ground level, as shown in Figure 1. Specimens of larger diameter were still intact but showed well defined cracks radiating outwardly from the electrodes. This was true even in the case of the 25-

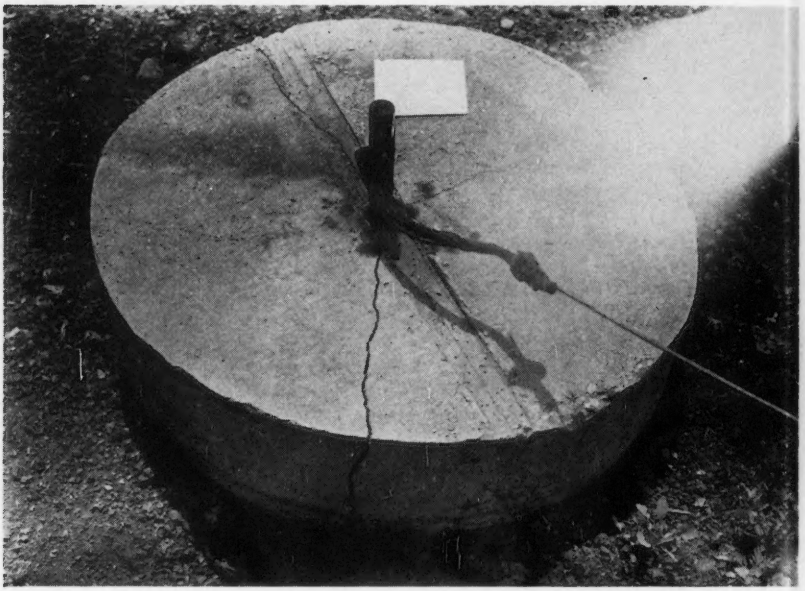


Figure 2—Specimen 14, 25-inch diameter, plain concrete, 1-3-5 mix, no covering. (July, 1945.)

inch diameter specimens as shown in Figure 2. It was evident that this cracking was due to the expansive force resulting from the electrolytic corrosion of the electrodes.

All of the plain concrete specimens subjected to the direct current potential developed these cracks regardless of the mix or admixture used. Figure 3 is a typical 13-inch diameter specimen with celite admixture and the cracks are clearly apparent in the figure.

It is apparent that tremendous expansive forces are set up by the electrolytic corrosion of the steel electrode. Not only were the 25-inch diameter plain concrete specimens cracked, but even those specimens encased in the steel pipe developed small cracks radiating from the electrode. However, due to the confining action of the steel casing, these cracks did not open up and become as well defined as in the case of the plain concrete specimens, as shown in Figure 4. The lower end of these specimens was not enclosed. To what extent the results would have been different had the specimens been completely encased in steel, including the lower end, is speculative.

Those specimens with asphalt waterproofing covering appeared to be in perfect condition as did also the specimens which had been subjected to 40-volt, 60-cycle alternating current since September 11, 1944.

It did not appear that anything would be gained by continuing these tests further, and accordingly they were discontinued in July 1945 and

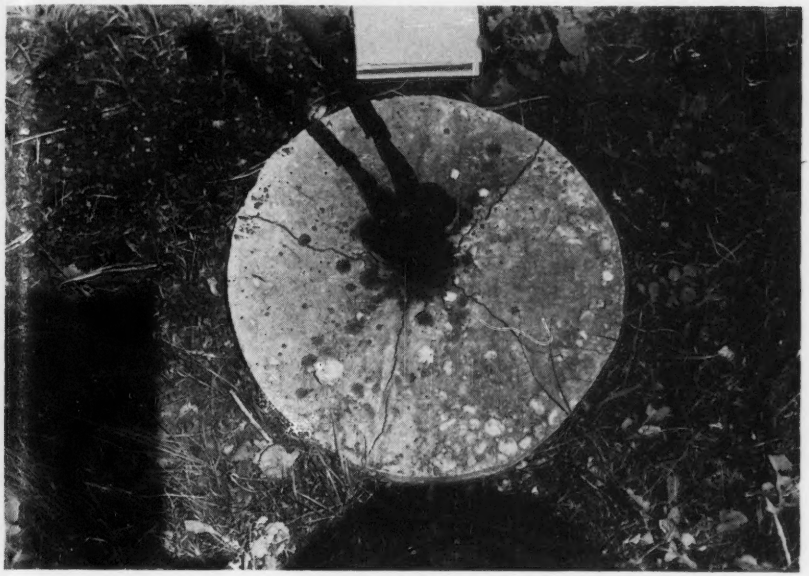


Figure 3—Specimen 43, 13-inch diameter, 1-3-5 mix with celite admixture but no covering. (July, 1945.)

the specimens were excavated for inspection. The condition of the small diameter plain concrete specimens revealed in Figure 5 shows one of them only partly excavated. The concrete was almost entirely disintegrated below ground level. This disintegrated concrete could be easily pulverized with the fingers.

The 3-inch and 5-inch diameter plain concrete specimens could not be removed intact and, in general, only a small portion of the concrete adhered to the top portion of the electrode when these specimens were removed, as shown in Figure 6. The very substantial shortening of the original 6-foot steel electrode by the electrolytic corrosion is also quite evident in this figure. A very distinctive pointing of the tips of the electrode will also be noted.

In the 13-inch diameter plain concrete specimens about one-half of the concrete remained with the steel electrode when the specimens were removed, as shown in Figure 7; and in the case of the 25-inch diameter plain concrete specimens the entire cylinders were removed intact. For these larger diameter specimens the surface of the concrete generally showed a deteriorated condition and could be very readily broken away and crumbled with the fingers to a depth of ¼ to ½ inch. In these larger diameter specimens, the concrete in the center of the steel electrode seemed to be reasonably sound except for the cracks previously described.

In Figure 8 is shown a specimen

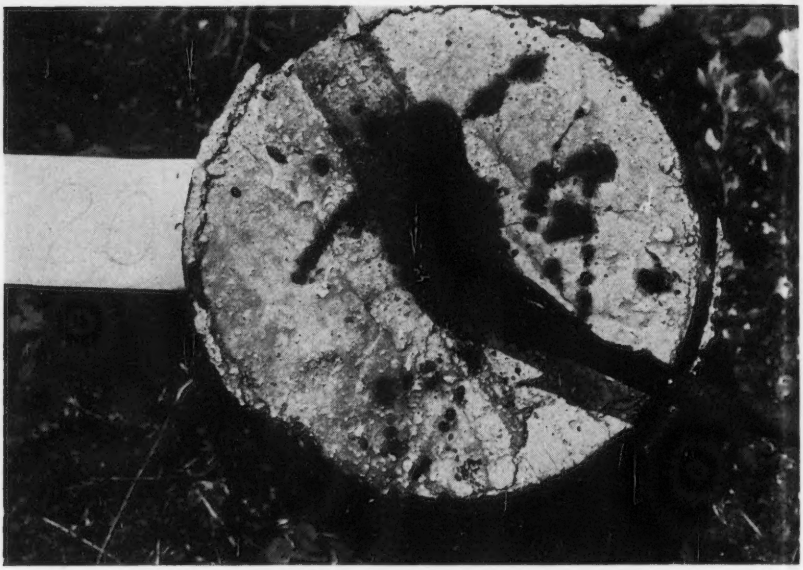


Figure 4—Specimen 20, 10-inch diameter, plain concrete, 1-3-5 mix, encased in steel pipe. (July, 1945.)

TABLE II

Modulus of Rupture of 2 x 2 x 12-Inch Test Beams Cut from Specimens in Electrolysis Test

Reference No.	Total Load, Lb.	Dimensions at Break, In.		Modulus of Rupture, Lb./Sq. In.	M_r Average	REMARKS
		Height h	Width w			
14A	430	2.04	1.98	522	....	25-in.
14B	480	1.99	1.93	628	....	d.c.
14C	440	1.94	2.02	579	576	Uncovered
20A	140	1.97	1.91	189	....	10-in. d.c.
20B	200	2.09	2.09	219	204	Pipe Covered
25A	200	2.07	1.95	239	....	13-in.
25B	450	1.96	2.07	566	....	d.c.
25C	440	2.00	1.96	561	442	Asphalt Covered
31A	240	2.02	1.99	296	....	13-in.
31B	380	1.98	1.98	490	....	a.c.
31C	540	2.03	2.00	655	480	Uncovered

Modulus of Rupture:

$$M_r = \frac{10P}{wh^2}$$

Third point loading. Total span 10 inches.
Distance between bearing elements 3.33 inches.

Rate of loading 220 lb. per minute.

Tested, Portland Cement Association, October 1, 1945.

of 5-inch diameter made with the 1-2-3 mix recommended by the Portland Cement Association. There appeared to be no significant difference in the performance of the specimens made with this mix and the 1-3-5 mix.

The specimens encased in steel pipe were removed intact from the ground and the pipe was then cut with an acetylene torch and removed, as shown in Figure 9. Electrolytic corrosion of this pipe is clearly evident at the lower end of the specimen. The concrete in these specimens did not show the disintegration that was evident in the uncovered concrete specimens, but the concrete when broken away from the reinforcing rod presented an appearance not characteristic of sound concrete. Also, a well defined layer of rust surrounded the steel electrode having almost a perfectly uniform thickness and being as perfectly finished as if it were a cardboard cylinder surrounding the rod. This rust had a blackish color and also a very fine texture and looked entirely different from the rust that formed on the plain concrete specimens which was similar in appearance to the type of rust that generally forms on steel subject to corrosion from air and water.

The asphalt-covered specimens when removed from the ground appeared to be in as good condition as when they were installed, as shown in Figure 10. When the asphalt covering was removed from these specimens and the concrete broken away from the electrode, it was found that the steel had maintained its surface condition with absolutely no indication of accumulated rust.

The specimens subjected to the alternating current were removed intact and appeared to be in good condition. The steel electrodes of these specimens, when the concrete was broken away, were similar to those in the asphalt-covered specimens, showing no evidence of accumulated rust.

The electrodes were removed from all of the test specimens, carefully pickled to remove the accumulated rust, and then weighed. Table III is a tabulation of the loss of weight of each electrode as determined by a comparison of the weight of each electrode before it

TABLE III

Loss of Weight by Electrolytic Corrosion of Steel Electrodes Used in Special Field Test

(Original weight of electrode—approx. 16 lb.)

Spec. No.	DESCRIPTION	Loss in Weight, (Lb.)
1	3-in. dia. plain concrete	8.5
2	3-in. dia. plain concrete	6.3
3	3-in. dia. plain concrete	6.4
4	5-in. dia. plain concrete	6.5
5	5-in. dia. plain concrete	5.9
6	5-in. dia. plain concrete	4.0
7	9-in. dia. plain concrete	3.8
8	9-in. dia. plain concrete	4.3
9	9-in. dia. plain concrete	3.1
10	13-in. dia. plain concrete	0.8
11	13-in. dia. plain concrete	2.2
12	13-in. dia. plain concrete	0.2
13	25-in. dia. plain concrete	0.4
14	25-in. dia. plain concrete	0.5
15	25-in. dia. plain concrete	0.7
16	6-in. dia. steel pipe encased	0.5
17	6-in. dia. steel pipe encased	0.7
18	6-in. dia. steel pipe encased	0.6
19	10-in. dia. steel pipe encased	0.7
20	10-in. dia. steel pipe encased	0.5
21	10-in. dia. steel pipe encased	0.6
22	5-in. dia. asphalt covered	0.0
23	5-in. dia. asphalt covered	0.0
24	5-in. dia. asphalt covered	0.0
25	13-in. dia. asphalt covered	0.0
26	13-in. dia. asphalt covered	0.0
27	13-in. dia. asphalt covered	0.0
28	5-in. dia. PCA Mix	5.0
29	5-in. dia. PCA Mix	5.6
30	5-in. dia. PCA Mix	3.8
32	13-in. dia. PCA Mix	2.8
33	13-in. dia. PCA Mix	2.9
35	13-in. dia. PCA Mix	3.3
50	5-in. dia. Celite Admix	5.1
43	13-in. dia. Celite Admix	2.4
44	5-in. dia. Morene Admix	2.5
46	13-in. dia. Morene Admix	0.7
48	5-in. dia. Hydrated Lime Admix	2.0
45	13-in. dia. Hydrated Lime Admix	3.6
84	5-in. dia. a.c. Test	0.0
31	13-in. dia. a.c. Test	0.7

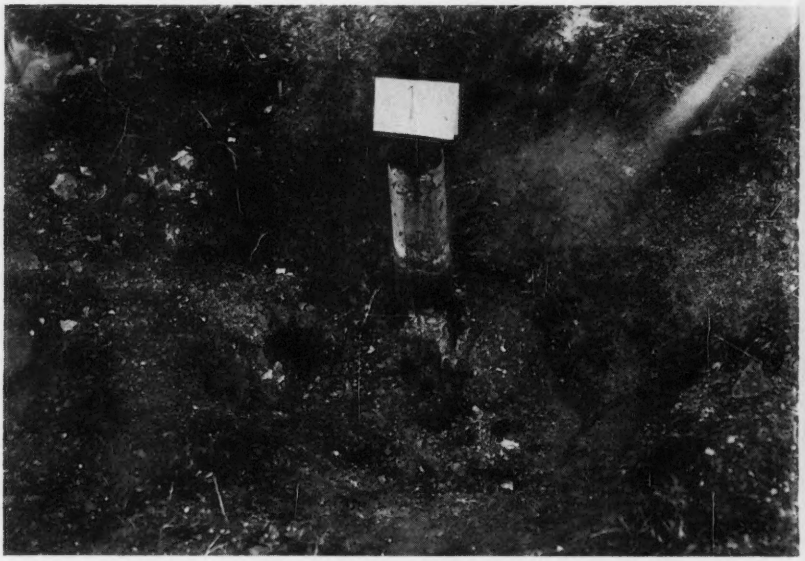


Figure 5—Specimen 1, 3-inch diameter of plain concrete, 1 cement, 3½ sand mix, with no covering, after being partially excavated. (July, 1945.)

Figure 6—Specimens of 3-inch and 5-inch diameter plain concrete after removal from ground. (July, 1945.)

Figure 7—Specimen of 13-inch diameter plain concrete after removal. (July, 1945.)

Figure 8—Specimen of 5-inch diameter, P.C.A. recommended 1-2-3 mix; partially excavated for removal from ground. (July, 1945.)

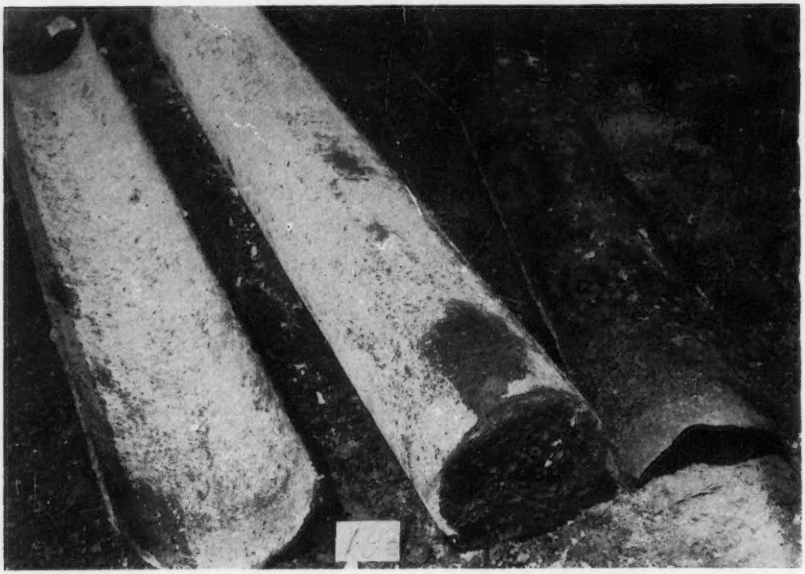


Figure 9—Specimen of 10-inch diameter encased in steel pipe, after being removed from ground and pipe cut away with acetylene torch.

Figure 10—Two specimens at left of 5-inch diameter with asphalt waterproofing coating. Two specimens at right of 5-inch and 13-inch diameter with hydrated lime admixture.

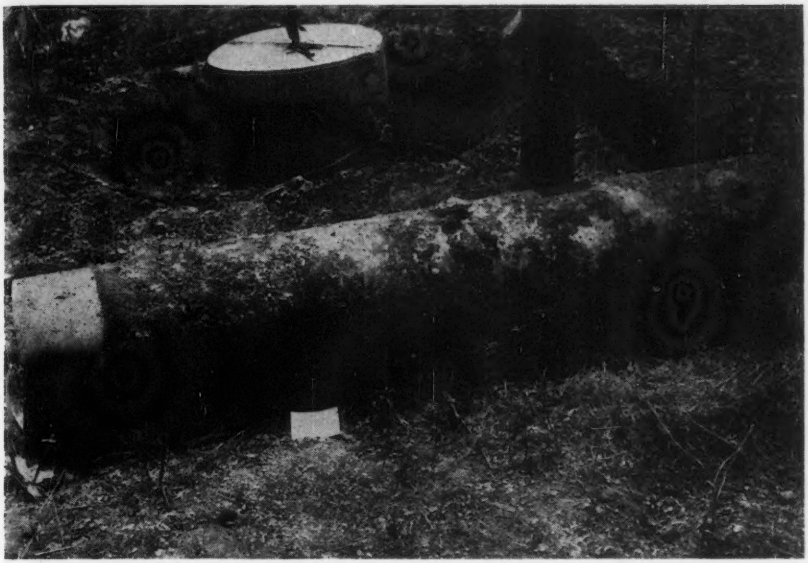


Figure 11—Specimen of 13-inch diameter plain concrete subjected to alternating current.

was placed in the test specimen with its final weight after the completion of the tests.

It will be noted from this table that the loss of weight for the plain concrete specimens decreased as the thickness of covering increased so that the loss was only about 3 percent with a 12-inch covering of concrete. The loss was also low with the steel encased specimens, and no measurable loss was found in any of the asphalt covered specimens. There is some evidence that the rate of loss was reduced with the Morene admixture compared with the plain concrete for specimens of equal diameter.

It was apparent from these tests that aside from the electrolytic corrosion of the steel electrode, which was anticipated, the electrolytic action had also produced a disintegration of the concrete. Accordingly, the Portland Cement Association was invited to have a representative inspect the condition of the specimens, and a report by Dr. L. S. Brown which describes the examination which he made of the specimens and gives his opinion of the cause of the concrete disintegration, is presented in Appendix A.

In order to further verify the observations of the deterioration of concrete as a result of electrolytic action, it was decided to make tests to determine the physical strength of small concrete beams of a size which could be cut from typical specimens taken from the field test. Accordingly, sufficient portions of

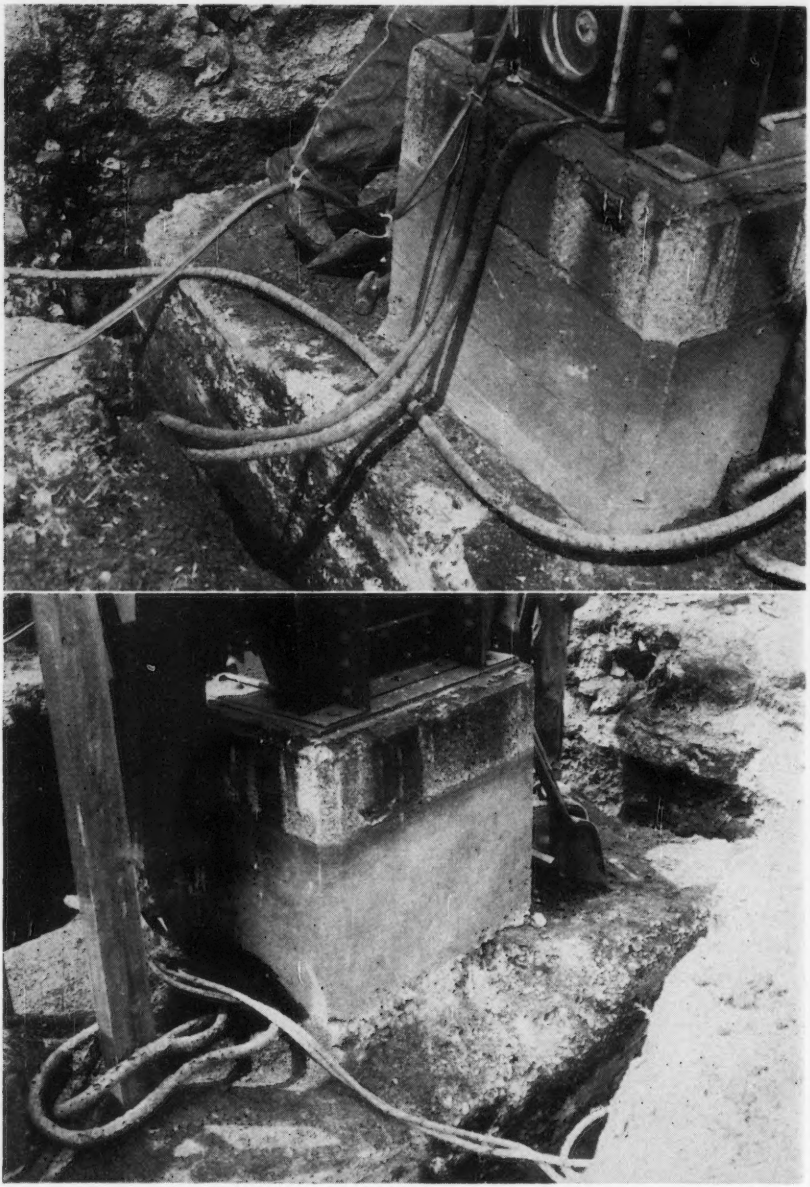


Figure 12—Catenary footing (top West, bottom East) near Roosevelt Road, Chicago, Illinois Central, excavated to show condition of concrete. (July, 1945.)

Figure 13—Catenary footing near Congress Street, Chicago, Illinois Central, excavated to show condition of concrete. (August, 1945.)

TABLE IV

Modified Cubes from Broken Ends of 2 x 2 x 12-Inch Test Beams Cut from Specimens in Electrolysis Test

Reference No.	TOTAL LOAD, LBS. A	TOTAL LOAD, LBS. B	Compressive Strength Lb./Sq. In. Average	REMARKS
14A	24,900	25,400	....	25-in.
14B	23,600	24,700	....	d.c.
14C	23,300	31,700	6,400	Uncovered
20A	15,200	16,500	....	10-in. d.c.
20B	16,500	16,900	4,069	Pipe covered
25A	23,100	22,200	....	13-in.
25B	21,700	19,700	....	d.c.
25C	22,600	17,900	5,300	Asphalt covered
31A	29,100	29,500	....	13-in.
31B	25,200	25,900	....	a.c.
31C	26,000	25,600	6,720	Uncovered

A, B=two ends of beams from flexure break.
Opposite load-bearing faces capped thinly with cement paste.
Load applied through 2x2x½-inch steel templates, accurately machined.
Rate of loading 25,000 lb. per min.
Tested, Portland Cement Association, October, 1945.

four different specimens were obtained, of a size which would permit three 2-inch x 2-inch x 12-inch beams to be cut from each. The specimens selected were a 25-inch diameter plain concrete, a 10-inch diameter with steel pipe encasement, a 13-inch diameter asphalt-covered, and a 13-inch plain concrete subjected to alternating current. Each of the small beams was first broken by bending on a span of 10 inches with two equal loads applied at the third points, and the results are given in Table II. Considerable variation in the strength of specimens so small is to be expected due to occasional occurrence of large aggregate, etc. It is thought, therefore, that too much significance should not be given to the results of beams 25A and 31A. However, in cutting beams for the 10-inch steel pipe-covered cylinder, it was apparent that the concrete in this specimen had been affected because the aggregate loosened easily and showed a distinct tendency to foul and break the cutting wheels. It was possible to get only two test beams from this specimen, and the results in Table II clearly show that the strength of the concrete in this specimen had been appreciably reduced.

After the test beams were broken in the flexural test, each end was subjected to a compressive test, and the results of this test are given in Table IV. Here again there is considerable variation in the measured compressive strength due to the small size of the specimens which were necessarily used. In this test as in the flexural test, the specimens cut from the 10-inch steel-encased pipe specimen showed distinctly inferior strength. It may be concluded from these tests that as a result of these conditions to which the various specimens were subjected in the special field test, the interior portions of the concrete from the 25-inch plain concrete specimen, the asphalt-covered specimen and the specimen subjected to alternating current, were not deleteriously affected.

Committee's Conclusions

Some additional work is contemplated with other types of specimens. These include specimens made with sulfate resisting cements and also additional steel-encased specimens having the lower end enclosed. However, it is believed that the following conclusions can be drawn from the results of the test to date:

(a) Increasing the thickness of concrete covering around reinforcing steel reduced the rate of electrolytic corrosion but did not effectively eliminate it to prevent cracking of the concrete.

(b) Admixtures included in the test were not effective in controlling electrolytic corrosion.

(c) The presence of the steel covering reduced the rate of electrolytic corrosion, but did not effectively eliminate it, and resulted in some deterioration of the physical strength of the concrete.

(d) The asphalt membrane waterproofing covering of concrete provided an effective means of eliminating electrolytic corrosion of reinforcing steel and deterioration of concrete.

(e) The electric potential maintained between the specimen and the ground resulted in a surface deterioration of the concrete of all uncovered specimens subjected to di-

rect current. The presence of some cinders, especially in the top portion of the sand and clay soil surrounding the specimens, may have been a factor in this deterioration, but this is a soil condition generally encountered near railway tracks.

Inspection of Catenary Foundations on Illinois Central Railway

Because of the excessive concrete deterioration which occurred in the special field installation previously described after only one year's duration of test, it was decided to excavate two catenary foundations on the Illinois Central Railway's suburban line near Roosevelt road and near Congress street in Chicago. These catenary foundations had been in service for 20 years and measurements had shown a maximum flow of 1 to 2 amp. from the structure into the ground during the interval of train passage. The structures are grounded to the return rail. Figure 12 shows two views of the catenary foundation near Roosevelt road after sufficient excavation had been made to disclose the surface condition of the concrete. A similar view of the foundation near Congress street is shown in Figure 13. At the left-hand side of this figure a portion of the concrete was broken away to expose a part of the anchor bolt so the extent of the corrosion on it could be observed. Some surface deterioration of the concrete had taken place in both of these footings, but it was difficult to determine by visual inspection whether this was due to electrolytic action or the result of poor concrete or insufficient tamping when it was placed. Generally speaking, however, it did not appear that these foundations had been seriously affected by the current flow that had taken place during the 20-year period. The foundations were still sound, there was no evidence of cracking from the anchor bolts, and that portion of an anchor bolt which was exposed did not show an abnormal amount of corrosion. The soil was mostly of clay, but contained some cinders.

Appendix A

Studies of Effect of Electric Current on Concrete

By Dr. L. S. Brown

Petrographer, Research Laboratory, Portland Cement Association

The experimental project of the Association of American Railroads, investigating the effect of electric current in concrete, was carried out at a plot of ground on the Illinois Central right-of-way at 23rd street, Chicago. This report presents the results of study of the experimental concretes, with some notes on examination of two catenary tower foundations in Chicago.

For the purpose of record, samples taken for this study are described as follows; none of them were from mixes with admixtures.

PCA Lot No.	AAR Spec. No.	DESCRIPTION
17311	10	13-in., 1-3-5, uncovered, sample near core
17312	10	13-in., 1-3-5, uncovered, sample near outside.
17315	10	13-in., 1-3-5, uncovered, sample from exposed top.
17318	10	13-in., 1-3-5, uncovered, scale from iron rod.
17313	35	13-in., 1-2-3, uncovered, sample near core.
17314	35	13-in., 1-2-3, uncovered, sample near outside.
17316	16	6-in., 1-3-5, covered with steel pipe.
17317	24	5-in., 1-3-5, layered bituminous cover.
17319	18	6-in., 1-3-5, steel covered, scale from iron rod.
17280	34	5-in., 1-3-5, uncovered, alternating current.

At the experimental plot the uncovered "direct current" cylinders exhibit prominently two effects. (a) There is a large scale longitudinal splitting of the concrete, obviously caused by expansion of the iron bar; this has nothing to do with electrolysis of the concrete, as such. (b) The concrete in the external surface of the uncovered cylinders is markedly disintegrated to a depth of 2 to 3 inches, so that the 3-inch cylinders are completely gone and the 5-inch are nearly so. Inner portions of the larger cylinders appear to be sound and intact. Alternating current and asphalt-covered (d.c.) cylinders show neither of these effects; steel-pipe covered cylinders show some longitudinal splitting but no disintegration except possibly near the bottom, which was left open.

Microscopical examination of the sound concrete, that is, exposed top of a.c. cylinders, asphalt-covered cylinders, pipe-covered cylinders, and inner portions of uncovered cylinders, fails to disclose any significant difference from similarly prepared and aged concrete not exposed to electrolysis.

In the disintegrating exterior portions of the uncovered cylinders, there is an abundance of a secondary mineral. The situation and structure of this mineral definitely indicate its formation to be the cause of disintegration. Qualitative microtests show it to be a sulfate, and optical properties identify it as the "low-sulfate" calcium sulpho-aluminate ($3CaO.Al_2O_3.CaSO_4.12H_2O$).

The problem of disintegration thus becomes one of discovering the source of the SO_3 entering into the formation of this mineral. Direct observations, and other considerations, indicate the source to be cinders, which are abundantly present in the ground of the experimental plot. (a) The original cylinder surface (PCA sample 17312) is covered with a thin skin and numerous tufts of gypsum ($CaSO_4.2H_2O$) crystals; in many instances these are directly associated with adhering fragments of cinder. (b) Cinders are notorious for presence of sulfides, which, in moist condition, easily oxidize to sulphuric acid. (c) There was no disintegration, and no occurrence of destructive secondary minerals, in the cylinders covered with steel pipe, although the record shows comparable or greater current to have passed. (d) The direction of accumulation of SO_3 is wrong, for, being negatively charged, it should move toward, and concentrate at, the anode (the iron bar), if the concrete only were involved.

Considering the whole project, and especially (d) above, it appears that the cylinder itself functioned as an electrode, positive with respect to the ground, and that the only significant effect of the applied potential on the concrete itself was to bring in negative SO_3 ions from the outside.

The major cracking and splitting of the cylinders, as previously noted, was traceable to expansion of the central positive electrode by the formation of a heavy scale on the surface of the iron bar. The scale merits a brief description, therefore, and it is further of interest inasmuch as there appeared to be two types, as occurring on the uncovered and the steel-pipe covered cylinders. The scale in the latter was uniform in thickness though thinner in general

than that in the uncovered cylinders where the thickness was quite variable.

In the uncovered cylinders the scale consists of two layers; the outer one is dark-colored, compact and formless, the inner layer being light brown and fibrous, at right angles to the surface of the bar and the outer scale; it is this layer that is variable in thickness. In the steel-pipe covered cylinders the scale has only the dark and formless layer. Both of these substances have been identified as hydrous iron oxides, though with the same chemical formula $Fe_2O_3H_2O$. The formless oxide is best identified as lepidocrosite and the fibrous oxide as goethite.

The interpretation of these observations is that the lepidocrosite is the product of purely electrolytic hydroxidation; its formation proceeded with expansion and pressure generation until the cylinder cracked, after which there was access of surface moisture and more normal conditions of "rusting" and the formation of the fibrous layer. The pipe-covered cylinders were restrained, and did not crack sufficiently to permit access of surface moisture and this second layer is not present. That expansion did occur, however, is shown by the small cracks radiating outwardly from the electrode which developed in the concrete while still incased in the steel pipe.

The most notable damage sustained by these experimental cylinders thus appears to be exterior sulphate disintegration and cracking by expansion of the iron electrode. No other significant effect of the passage of the electric current was observed, other than that some of the concretes, principally that in the steel-pipe covered cylinder, seemed "dead," that is, it had no "ring" when struck with a hammer, with easy parting between paste and aggregate.

It is possible that the dead reaction is the result of compression crushing between the expanding central electrode and the restraining pipe. The pipe was not ruptured but the concrete cylinder split on removal of the pipe. As evidence of actual pressure, consider the thickness of the oxide scale which was about 1/16-inch. Doubling this (for the opposite sides) and assuming one-half of it to have been occupied by steel prior to oxidation, there is a net reduction of 1/16-inch in the 5-inch diameter of concrete in the (6-inch) cylinder, a reduction of 1¼ percent. This is a very significant volume change for concrete.

During and subsequent to the above studies, the writer was present at the uncovering and examination of two catenary tower supports, each consisting of a pedestal and base. These two had been selected for excavation because, in a recent survey of towers, they had shown the highest current leakage. The base is about 4 by 8 feet and some 15 to 18 inches thick; in both supports the concrete shows considerable surface honeycomb, with other evidence of initially poor quality. Despite this, and 20 years' service, the concrete was sound and firm. The pedestal is approximately a 2½-foot cube, extending a few inches above ground. Near the corners, the four 1¼-inch anchor bolts pass vertically through the cube and extend partly into the base. It was obvious in each case that a better quality

concrete was used in the pedestal.

At one of the tower supports, one of the anchor bolts was exposed to view by breaking away some of the concrete cover; this was facilitated by a small crack in one corner of the pedestal, near the base, but still required some heavy sledge and bar work. There was a thin stain of rust on the surface of the bolt, but nothing at all in comparison with the scale on the rod electrodes in the experimental cylinders. On further breaking out the concrete, following down the bolt into the footing, the concrete became softer and more easily removable. At a depth of 5 or 6 inches the surface of a block of wood was encountered; apparently this was a piece of 2 by 4 or 2 by 6 used to hold the anchor bolt while placing the concrete of the footing. The operation was discontinued at this point.

Insofar as these observations bear upon the problem of current leakage, it should be noted that the effects produced by the passage of electric current through the experimental cylinders were not observed in the concretes of either of the tower bases. Another noteworthy feature of the field experiment was that the resistance of the cylinders increased with time; at five months the readings of current passage showed only 14 to 30 percent of the initial readings. The only tangible damage evidenced by the tower bases was the soft spot around the piece of damp wood in one of them. It is easily possible that the associated soft zone in the concrete extended well toward the bottom of the footing and, also, being in contact with the anchor bolt, that it facilitated grounding of the current.

Conclusions

In conclusion, the observations reported herein point out several suggestions for possible future investigation. In the first place, since tricalcium aluminate is the constituent in cement that is vulnerable to sulphate attack, and since cinders are likely to be prevalent in many areas of railroad construction, it might be well to test several cements, representing different contents of tricalcium aluminate. Then cylinders duplicating those previously used might be subjected to electric current in a soil free from sulphate (or cinders). Again, duplicate cylinders might be buried in cinders without application of current, to evaluate the role of current in sulphate attack.

Corrosion Abstracts

CORROSION TESTING

The Accuracy of Corrosion Tests.

A. S. AFANAS'EV AND M. K. SHELUD'KO, Korroziya i Bor'ba, s Nei. **7**, No. 3, 22-29 (1941); Aluminum and Magnesium, **2**, No. 8, 34 (1946) May.

Ten groups of corrosion tests in atmosphere, water and three percent sodium chloride were applied to 6841 samples of steel and cast iron. With n (the number of samples in any test) equaling 5-7, the minimum weight loss should exceed a certain value for satisfactory accuracy. n depends on the type of test and the material being tested; in the present cases it varies from 30-400 grams per square meter. Increasing accuracy as a result of appreciable prolongation of test over this amount is less apparent than that due to increasing n. Increasing n over 10 has practically no effect on the accuracy. Generally, only two places in the weight-loss figures are significant. Corrosion samples with an area of about 25-50 square centimeters ought to be weighed to within one mg. if the expected weight loss is 100 mg. per sample.

Corrosion Resistance of Aluminum Welds in Nitric Acid. R. B. KHMEL'NITSKAYA, Korroziya i Bor'ba s Nei, **7**, No. 3, 29-33 (1941); Aluminum and Magnesium, **2**, No. 8, 34 (1946) May.

Aluminum alloy oxyacetylene-welded samples were tested in nitric acid as welded, as peened and annealed at 390°, and as peened and water-quenched from 500°. The greatest attack was noted in 15 and 50 percent nitric acid. At 60° rate of corrosion was about 20-40 times that at room temperature. For best corrosion resistance, a high-purity weld rod should be used, the peening should be done with particular attention to the contact zone, and the welded joint should finally be heated to 380-400° and cooled in air or water.

Oxygen and Hydrogen in Steel Weld Metal—Methods of Determination. T. E. ROONEY, Welding, **14**, 178-184 (1946) Apr.; Mond. Gen. Refer. Sheet, Ser. No. 477, 13 (1946) Apr. 27.

Critical summary-review of the published literature of the subject.

Corrosion Resistance of Zinc-Cadmium Alloys. N. S. GORBUNOV, Compt. rend. (Doklady) Acad. Sci. U.S.S.R., **27,** 228-231 (1940); J. Inst. of Met. & Metall. Abs., **13,** 123 (1946) Apr.

Data concerning the corrosion of zinc-cadmium alloys in 10 percent acetic acid and in normal sulfuric acid are recorded. The corrosion-composition curves have the same general shape as the melting point-composition curves, corrosion resistance being greatest for alloys of eutectic composition and high for alloys rich in cadmium.

Aluminum in the Coal Gas Industry. Aluminum & Magnesium, **2,** No. 6, 18-19 (1946) Mar.

Aluminum is superior to other ferrous and non-ferrous metals in its resistance to corrosive fumes and liquors indigenous in the production of coal gas and products of gas consumption. Reaction of aluminum to the various chemicals involved is discussed in detail. Tests of 10 metals for corrosion resistance to gas combustion products showed: lead, tin and solder were very resistant: aluminum, brass and copper had good resistance; nickel, iron, galvanized iron and zinc had poor resistance.

Corrosion Resisting Properties of Electrodeposited Tin-Zinc Alloys. R. M. ANGLES AND R. KERR. Engineering, **161,** No. 4185, 289-292 (1946).

Humidity chamber, salt spray, hot water and outdoor exposure tests of flat and deformed specimens of steel with electrodeposited coatings of tin 92-28, zinc 8-72, tin, cadmium, zinc and hot-dipped zinc, showed the 78 tin-22-zinc coating to be superior. Treatments in various oxidizing solutions indicated that 10-30 seconds in 20g per liter. chromic acid at 80° C. or 30-60 seconds in the cold solution provided the best protective oxide. Illustrations show the appearance of the specimens after testing.

Rusting of Mild Steel in Contact with Copper. G. SEELMEYER, Korros. und Metallschutz, **19,** 38-44 (1943); Brit. Abs., BI, 69 (1946) Feb.

The corrosion of steel plates with copper inserts by distilled water and one percent sodium chloride solution is investigated. The rate of attack by the latter is roughly twice that by water. Generally, as the ratio of copper area to iron area is increased, the rusting and loss in weight are diminished. After 60 days immersion, weight loss was greatest with iron alone. Only after 10 and 24-day tests is the weight loss of iron alone greater than that when small areas of copper (up to 10 percent are present. Rust is uniformly distributed except for a small spongy ridge at the copper-iron junction. After cleaning, dark layers can be seen around the copper area: these are shown microscopically to be ferric oxide. In all cases, after a time an almost constant potential is reached which is negative except for copper alone. This constant potential is reached more quickly with small copper area.

Corrosion Resistance of Chromium-Plated and Surface Conditioned 13 Percent Chromium Steel. W. E. MOLINS, National Cash Register Co.; Am. Electropl. Soc. Monthly Rev., **33,** 401-405 + (1946) Apr.

An extensive laboratory investigation of 13 percent chromium steel included study of the following variables: surface finish, passivation and

chromium plating. Corrosion resistance was measured by exposure to salt spray test and to gasoline saturated with water or salt solution. Atmospheric corrosion tests were also initiated, but have not yielded sufficient data for conclusions. Data are tabulated which show effect of chromium plate thickness on salt spray resistance, effect of surface condition (passivated and chromium-plated) on salt spray resistance, also of carburetor parts in same test. Valve parts are shown after exposure. With the exception of the one tested in straight 100 octane gasoline with three percent sodium chloride solution, none of the chrom-flashed specimens showed any change after 10 days of exposure. All passivated valves, except the one tested in gasoline alone, broke down completely. A chromium plate of 0.00005-inch is superior to a passivated or immunized surface.

GAS AND CONDENSATE WELL CORROSION

Extensive Water Analysis in Cycling Fields Yields Useful Information on Corrosion. Oil & Gas J., **44,** No. 47, 270 (1946) Mar. 30.

An extensive program of analysis of waters from cycling wells completed by the corrosion research project committee of the Natural Gasoline Association of America has yielded some significant information on the physical and chemical differences of corrosive and noncorrosive fields.

The data indicate that appreciable quantities of iron and organic acids in well waters do not necessarily indicate a high rate of corrosion or that corrosion is present. The data do indicate, however, higher average temperatures in the corrosive than in non-corrosive fields. Other work on this subject indicates the likelihood that the corrosive attack is an acid type of attack that is partly inhibited by some naturally occurring inhibitor in the corrosive wells, and is substantially completely inhibited by the same naturally occurring inhibitor in non-corrosive wells. Data are tabulated on the water-survey.

Carbon Dioxide in a Natural Gas-Condensate System. F. H. POETTMANN AND D. L. KATZ, Univ. of Mich., Ind. and Engr. Chem., **38,** 530-34 (1946) May.

Equilibrium constants for carbon dioxide in a natural gas-condensate system have been determined over the range one to 10 mole percent carbon dioxide. Densities and molecular weights have been determined for saturated vapor and liquid phases for 24 hydrocarbon mixtures containing carbon dioxide at temperatures from 100° to 250° F., and pressures from 500 to 2900 pounds per square inch absolute. It is shown that the lower the molecular weight of the hydrocarbon in the binary carbon dioxide systems, the greater will be the deviation of the carbon dioxide from ideal behavior. Equilibrium constants of carbon dioxide in the natural gas-condensate system deviate most from the ideal equilibrium constants. Since the multicomponent mixtures consisted of over 60 mole percent methane, the methane-carbon dioxide system may be expected to show wide deviations from ideal solutions.

Sodium Chromate Effective in Combating Corrosion in Gas Wells. C. K. EILERTS, Oil and Gas Jour., **45,** No. 2, 124 + (1946) May 18.

Sticks of sodium chromate dropped into a gas well which is subject to corrosion maintained inhibiting concentrations for more than two hours. The sticks can be injected into tubing against the fluid flow when the mean fluid velocity is not greater than 11 feet per second. Many improvements in the method are necessary before the treatment becomes practical.

GENERAL CORROSION

Corrosion in the Refrigerating Industry and Its Control. A. STEINBACH, Gesundh.-Ing. **67,** 67 (1944); Dept. Sci. Ind. Research (Brit.), Water Pollution Research, Summary Current Lit., **17,** 168 (1944); Aluminum & Magnesium, **2,** No. 8, 34 (1946) May.

Types of corrosion occuring in refrigerating plants include corrosion occurring at the level of the brine in tanks and pipes, where fluctuating level causes alternate wetting and drying of metal, pitting, galvanic corrosion, intercrystalline corrosion (in cast iron structures, mainly), and corrosion from stray currents from electric motors and generators. Preventive measures for each type are described.

Corrosion. M. G. FONTANA, Ohio State Univ. Eng. Sta. News, **18,** 27-31 (1946) Feb.; The Metals Review, **19,** No. 4, 8 (1946) Apr.

General discussion of types of corrosion and methods of combating them.

Corrosion of Underground Structures in Gas Plants. C. F. MEYERHERM, ALBERT F. GANZ, INC., Paper before A. G. A., Tech. Sect., Jt. Prod. & Chem. Comm. Confer., N. Y. C., June 3-5, 1946; A. G. A. Preprint, 1946, 6 pp.

Since gas plants are frequently located on tide water or areas where soil and atmospheric conditions are naturally conducive to corrosion of metals, causes and method of combating soil corrosion are discussed. Causes include galvanic cells, stray electric currents and anaerobic sulphate-reducing bacteria. Extensive discussion of cathodic protection, and elimination of stray currents.

Corrosive in Crevices. E. H. WYCHE, Titanium Alloy Mfg. Co., L. R. VOIGT, AND F. L. LAQUE, International Nickel Co., Paper before Electrochem. Soc., 89th Gen. Mtg., Birmingham, April 11-13, 1946; Electrochem. Soc., Preprint **89-23,** 265-278 (1946).

The nature of corrosion in crevices and its occurrence are described. Sea water tests on various crevice sealing compounds are reviewed. Practical suggestions for avoiding this type of corrosion are made. Types of corrosive media most likely to be associated with corrosion within a crevice are those in which other forms of local loss of passivity and subsequent local attack are encountered, e.g., salt solutions, reducing acids, and, under peculiar circumstances, oxidizing acids such as nitric acid. Data on effectiveness of various sealing compounds on chrom-nickel iron alloys at Kure Beach are listed and discussed. Stainless steel pipes are shown.

Reminiscences of Early Corrosion Research. F. N. SPELLER, National Tube Co., Paper before Fellows of Battelle Memorial Inst., Nov. 30, 1945; Corr. & Mat. Prot. **3,** No. 3, 6-8 (1946) Mar.

High points in the early history of corrosion tests and protection are listed chronologically and discussed. Outstanding research projects are mentioned, including the Kure Beach investigation designed and inaugurated in 1935 by F. L. LaQue.

INHIBITORS

Bacterial Deterioration of Cutting Oil Emulsions. L. LIBERTHSON, Lubrication Eng., **1,** 103-106 (1945) Dec.; Corr. & Mat. Prot. **3,** No. 4, 26 (1946) Apr.

Sulfur bacteria were found to cause deterioration of cutting-oil emulsions. These bacteria also may be responsible for failure of so-called ruts-inhibitive compounds, and even paints, and of preservative oils specified and used by the Army and Navy. Trouble was overcome by aeration of emulsion.

INSPECTION

Penetron Detection of Corrosion Inside Distillate Producing Equipment. F. B. GORDON AND P. H. LIPSTATE, JR., Penetron Service Co., Oil Weekly, **122,** No. 3, 38-9 (1946) June 17.

Describes the applications of the Penetron in the detection of corrosion in piping, tubing, etc. The apparatus makes use of penetrating gamma rays. Illustrated.

A Method for Predicting Failure of Metals. P. E. CAVANAGH, B. ALLEN, Du Mont. Labs., ASTM, **1946** Preprint, No. 23, 1-4.

The foregoing demonstrates that high-frequency core losses can be use to detect incipient failure in metals where such failure is preceded by plastic deformation. The continuous inspection of mine-hoist rope in service is a logical application of this test. This is described. Cyclograph readings show comparisons of stress-strain and stress-core loss curves for SAE 1020 and 1095, Everdur, copper and brass.

METAL FAILURE

Aluminum Copper Alloys. S. A. SAGE, Mech. World & Eng. Record, **119,** 175-176 (1946) Feb. 15; Corr. & Mat. Prot., **3,** No. 4, 22 (1946) Apr.

A critical review. Copper can be added to aluminum in all proportions, but the most useful alloys at the aluminum end of the series limit it to about 12 percent. Corrosion resistance due to the formation of the constituent $CuAl_2$ in the microstructure, is below that of pure aluminum, but is better than that of the aluminum-zinc or aluminum-copper-zinc alloys. Properties of the aluminum-copper alloys show that these alloys are heavier and less corrosion resistant than pure aluminum.

Corrosion Protection of Flying Boats. J. J. HENDERSON, Aviation Maintenance, **5,** 44-45 (1945) Dec.; Corr. & Mat. Prot., **3,** No. 4, 24 (1946) Apr.

Skins of hulls of flying boats consist of sheets of anodized 17ST or 24ST, and in some cases, Alclad. From a corrosion point of view, Alclad surfaces are superior to anodized Dural. In cases where Alclad sheets have corroded, metallographic examination has indicated that depth of corrosion has been confined to the

cladding. On the other hand, Alclad surface is relatively soft, which tends to mar the appearance and does not form a good paint base. Experience has shown that optimum corrosion protection and appearance consists of one coat of zinc chromate primer, specification AN-11-656b, followed by two sprays of aluminum alkyd resin varnish.

Ships in Moth Balls. Popular Science Monthly, **148,** 126-127 (1946) Mar.

Describes briefly dehumidification work on the reserve fleet being done in order to prevent corrosion of various metal parts of ships.

Carbon Absorption of 18-8 Stainless Steel. W. G. HUBBELL, Ryan Aeron. Co., Iron Age, **157,** No. 25, 56-59 (1946) June 20.

Several exhaust manifolds which failed in service were subjected to a series of laboratory tests to determine whether carbon pickup from exhaust gases contributed to their failure. Conclusions confirmed that there is a carbon pickup (varying in specimens between 0.023 to 0.06 percent, but corrosion resistance did not appear to be materially reduced, and there was no evidence of intergranular corrosion, manifolds having failed because of scaling of metal at excessive temperatures. Two reasons why the carbide network ascertained as being formed did not cause intergranular corrosion may be: (1) carbides, formed over extended periods at relatively low temperatures are less harmful than those formed suddenly (as in the case of sensitized Type 302); or (2), perhaps a progressive intergranular attack keeping pace with build-up of carbides, is removed as rapidly as it occurs by the rush of high velocity exhaust gases which scour the surface. Microstructures are shown of three manifolds which failed and one which did not fail in 4000 hrs. Carbon analyses are given.

No-Carbon Stainless Steel. Materials & Methods, **23,** 1486 (1946) May.

A new answer to the problem of carbide precipitation in stainless steels may be found in a still experimental, but extremely promising, stainless steel containing less than 0.03 percent carbon on which one large company is now working. This amount of carbon is within the carbon solubility range, hence stabilization would not be required to prevent carbide precipitation during processing or use.

Antimony in 18-8 and Plain-Chromium Stainless Steels. Iron Age, **157,** No. 20, 44-50 (1946) May 16.

Results of extensive investigation of the effect of additions of antimony to 18-8 and plain chromium stainless steels (covered by U. S. Patents 2,334,869 and 2,334,870) are discussed. The tests, which embraced 36 compositions of stainless steels, indicated that the effects of such additions are varied and inconsistent with respect to hot-workability, machinability, physical properties and corrosion resistance. Tables and photomicrographs are given.

Relation of Strain Aging to the Stress-Corrosion Cracking of Mild Steel. J. T. WABER AND H. J. MCDONALD, Ill. Inst of Technology, Welding J., **25,** No. 4, 223-s-234-s (1946) Apr.

Previous investigations on the re-

lation of strain aging and caustic embrittlement, the stress-accelerated precipitation theory of corrosion cracking, and the free-nitrogen factor theory are reviewed. Further test results are given from work carried on in the Corrosion Research Laboratory of the Illinois Institute of Technology, which tests demonstrated that removal of nitrogen followed by its reintroduction caused the loss and reinstatement of the cracking tendency. Tables and graphs give the following: correlation between aging and cracking times; correlation between free nitrogen and cracking time, with effect of quenching temperatures; correlation between free nitrogen and extent of aging composition and properties of steels used, with effect of quenching temperatures; effect of applied stress on cracking time; aging of unstressed samples at 60° C.; effect of applied stress on aging at 105 C.; and effect of nitriding on susceptibility to cracking. Ninety references are given.

The Fatigue Strength and Notch-Sensitivity of Electric-Arc. Weld Metal. C. SCHAUB, Tek Tidskrift, **75,** 1263-1266 (1945); Mond Gen. Refer. Sheet, Ser. No. 475, 6 (1946) Apr. 6.

Tests reported show that the notch sensitivity of weld metal is greater than is generally believed.

Influence of Steel Sheet Linings in Molds Upon Crystallization of Steel Ingots. M. P. SLAVINSKI, L. R. EDELSON AND A. YE VOL, Metallurg. **8,** No. 3, 66-68 (1933).

Results of earlier experiments on the effect of aluminum-foil or aluminum-sheet linings on the crystallization of aluminum ingots are given. 100-lb. steel ingots, containing 3.26 percent nickel were poured in molds with and without steel sheet linings, under otherwise strictly identical conditions. Behavior of linings in pouring, and influence of linings on size of columnar crystals and on crystal structure of ingots in general are discussed.

Correspondence Stress-Corrosion Cracking of 18-8. R. FRANKS, Union Carbide and Carbon Res. Lab., Metal Progress, **49,** 563-565 (1946) Mar.

The writer does not support the inference made by Mr. Monypenny, in correspondence, of Nov., 1945, that cold-rolling austenitic stainless steels, used in hospital equipment, made them more subject to stress-corrosion cracking. Data which shows the reverse to be true is presented. Under simultaneous influence of stress and corrosion, the cold-rolled steels withstand higher stress than the annealed steels. Data on 17-7 and 18-8 steels in magnesium chloride solution previously published are given.

Properties and Characteristics of 27 Chrom-Iron. H. D. NEWELL, Babcock & Wilcox Tube Co., Metal Progress, **49,** 977-991 + (1946) May.

Paper represents a compendium on the mechanical properties and structural characteristics of 27 percent chrom-iron alloy and tables are given. The studies were intended primarily for manufacturers of raw materials for synthetic rubber. The relative chemical inertness of the 27 percent alloy under alternate reducing and oxidizing conditions, such as are encountered in the catalytic dehydrogenation of normal butane, has warranted the use of this ma-

terial for equipment for making butadiene.

Toughness and Fracture of Hardened Steels—TP2020. M. A. GROSSMANN, Carnegie-Illinois Steel Corp., Howe Memorial Lecture, 1945; Metals Technology, **13,** No. 3, 1-41 (1946) Apr.

A general picture of the effects of the tempering process on the toughness of steel was arrived at through notched-bar impact tests of quench-hardened steels SAE 2340, 3240, 4140, NE9465, 9445, 98V65 and WD4150. Microstructures of fractures are shown, and many graphs. Effect of ferrite precipitated in grain boundaries on energy absorbed in notch-bar impact tests, effect of tempering temperature on notch-bar toughness, and effect of intervening refrigeration in quenched and tempered steels, are among results graphed or tabulated.

A New Copper-Phosphorus-Lead-Nickel Alloy. V. A. GRODSKY, U. S. Naval Gun Factory, Metal Progress, **49,** 970-972 (1946) May.

A discussion of the development of a copper, phosphorus, lead, nickel alloy. Typical properties are tabulated and the foundry practice is described. The alloy has many advantages: (1), melting and casting temperatures are low; (2), metal is fluid, fills out the mold and has a low shrinkage; (3), can use dry sand, skin dried green sand, and chill molds; (4), has high density and is suited for P castings; (5), has good machinability; (6), no tin used; (7), can be welded with gas or electricity; (8), bearing properties are as good as the best copper-lead-tin bronzes and (9), corrosion resistance is higher than that of phosphorus bronze in ordinary exposures in service.

Gray Iron Wear Resistance. F. G. SEFING, International Nickel Co., Am. Fndryman, **9,** No. 6, 77-79 (1946) June.

Gray microstructures having the best wear properties and those vulnerable to wear are shown and briefly discussed. A complete and fine pearlitic matrix with A. F. A. Type A graphite favors good wear resistance while coarse pearlite, free ferrite or cementite in the matrix, and A. F. A. Types D and E graphite decrease wear and gall resistance. Effectiveness of inoculant control is discussed.

Influence of Thermal Stresses and Structural Transformations upon Dimensional Changes in Hardening. S. S. SCHTEINBERG AND S. A. ELGOT (In Russion), Stal (Moscow), **1,** No. 2-3, 82-85 (1941).

Experimental study of movement of copper, pure iron and steel in hardening. Effects of (a), purely thermal stresses, (b), thermal stresses plus allotropic transformation without, and (c), with quenching on dimensional changes are given. A manganese tool steel and a chrom-tungsten-manganese tool were studied. Forces set up by thermal stresses in non-uniform cooling, factors influencing residual deformation, effect of tensional stresses created by allotropic transformation in pure iron, effect of stresses in steel introduced by martensite transformation and associated with an increase in volume upon movement of steel, effect of quenching from temperatures entailing overheating upon movement of steel, and comparative effect of mar-

tensite transformation and thermal stresses upon dimensional changes of steel, are discussed. Tables show linear dimensions and size of cylinders of copper, iron, manganese steel and chrom-tungsten-manganese during heat treating.

Deterioration of Analytical Weights. A. F. H. WARD, Chem. & Ind., 393 (1945) Dec. 15; Corr. & Mat. Prot. **3,** No. 4, 22 (1946) Apr.

Observations indicate that gold plating is unsuitable for analytical weights, as it is very soft and easily damaged. Corrosion products, formed with the base metal and facilitated by the electrolytic couple set up, force up more gold plating and corrosion spreads rapidly. Nickel is liable to suffer chemical attack by which the surface polish is destroyed. Even stainless ferrous alloys corrode in laboratory atmospheres. Manley's investigation (Phil. Mag., 1933, No. 7, p. 489) showed that chromium plating was the best of the finishes tested. A further cause of corrosion can be acid from glue used to line boxes with velvet, so that a plain hardwood box is recommended. The author recommends use of rhodium plating.

Deterioration of Analytical Weights. W. C. JOHNSON AND S. J. KENNEDY, Chem. & Ind., **1946,** 66, Feb. 9; Corr. & Mat. Prot., **3,** No. 4, 22 (1946) Apr.

Comments on letter by A. F. H. Ward (above). Manley's investigation consisted of measuring weight of removable film formed on weights during storage. Because chromium forms a very adherent film, this gives it an apparent but fictitious advantage. Authors conclude that chromium is not a good finish for weights, and that rhodium may have some advantages over gold, but the best course is to construct the weights from a non-corrodible alloy such as a non-magnetic nickel-chromium alloy.

Influence of Strain Rate and Temperature on the Mechanical Properties of Monel Metal and Copper. D. J. MCADAM, JR., G. W. GEIL AND D. H. WOODARD, Nat. Bur. of Stand., ASTM Preprint, No. 54, 1-49 (1946).

The relation between creep rate, temperature, flow stress, breaking stress, and ductility, is discussed, and a general view of the influence of strain rate and temperature on the mechanical properties of Monel and oxygen-free Copper between 188° C. and the melting points is present. Thirty-one graphs and microstructures are shown. Thirty-one references.

The Effect of Carbide Spheroidization Upon the Rupture Strength and Elongation of Carbon-Molybdenum Steel. S. H. WEAVER, General Electric Co., A.S.T.M. Preprint, No. 55, 1-11 (1946).

Specimens from a carbon-molybdenum-steel plate were treated to obtain 12 different conditions of the steel by varying heat treatment and amount of spheroidization. Each condition of the steel previously had been tested in long-time creep at 900 and 1000° F. Using the same plate of steel, specimens in the 12 different conditions were subjected to long-time rupture-stress and elongation tests at 900 and 1000° F. The following conclusions were reached: (1), there is a tendency for all conditions of steel to approach a common, stable rupture stress, (2), dur-

ing long service life tested rupture stress for a period of 10,000 hours does not decrease nearly so much as creep stress; (3), rupture elongations for all conditions of steel except those with initially spheroidized carbons rapidly drop with time; (4), extrapolation for rupture stress and elongation over the 10,000 to 100,000-hour test period is questionable; (5), the creep-stress conclusion that 1000° F. is near the practical limit in design stress is not invalidated by the data.

The Effect of Notches on Static and Fatigue Strength. D. W. DRAKE, Lockheed Aircraft Corp., J. Aeronautical Sciences, **13,** 259-269 (1946) May.

The factors governing notch strength, both from a static strength and from a fatigue strength standpoint, are discussed. It is shown that an increase in yield ratio will usually increase the static efficiency of notched specimens, but that this increase may be limited by the ability of the material to strain. The use of the high-strength aluminum alloys in airplane structures may result in appreciable reduction in structural weight for the same static strength, but this may be accompanied by a reduction in the fatigue strength of the structure. Graphs include variation of net and gross area efficiently with depth of notch for SAE 3140 steel in tension. Twenty-four references.

Metallographic Observations of Ball Bearing Fatigue Phenomena. A. B. JONES, General Motors Corp., ASTM Preprint 45, 14 pp. (1946).

What happens to the internal structure of bearing races, during their life span to spalling, was studied, using SAE 52100. The relation of areas of troostite, which appear, to fatigue life was analyzed together with stress studies. Conclusion was that gray lines produced when ultimate fatigue life is approached result from plastic flow caused by shear stresses above the reduced elastic limit of troostite material at point of maximum heat generation. It is thus possible by correct interpretation of metallographic observations to estimate closely the load to which a particular bearing has been subjected, and the length of time it has run, provided operating speed is known. Microstructures are shown.

Investigation of Graphitization at Detroit. R. M. VAN DUZER, I. A. ROHIG AND A. MC CUTCHAN, Detroit Edison Co., Paper before ASME, Jt. ASTM-ASME Res. Comm. on Effect of Temperature on Properties of Metals, Nov. 27-Dec. 1, 1944; ASME, Graphitization of Steel Piping, Sept. (1945) 57-63.

A report on an investigation of welded joints of carbon steel and carbon-molybdenum piping in Detroit Edison power plants. No serious case of deterioration was found, but evidence of the dispersed type of graphite was found in carbon steel joints which had been in service at 835° F. for 60,000 hours, and in high-aluminum carbon-molybdenum welded joints in service at 900° F. for periods up to 20,000 hours. No graphite was found in low-aluminum carbon-molybdenum pipe joints in service at 900° F. for periods up to 43,000 hours. Welded samples of high and low-aluminum type carbon-molybdenum pipe heated for 3300

hours at 1000-1060° F. in a laboratory furnace confirmed the conclusion that the low-aluminum variety had greater resistance to graphitization. Microstructures are shown, and data are tabulated.

Hydrogen in Metal Arc Welds. C. B. VOLDRICH, Battelle Mem. Inst., Paper before AWS, Cleveland Sec., May 10, 1946; Steel, **118,** No. 20, 147 (1946) May 20.

Hitherto unpublished information on cellulosic vs. low-hydrogen (lime coated) electrodes was disclosed. Studies of under-bead and toe cracks in welds of many types and grades of steels, including NE 8620-26-30-35-40-45 and SAE 4130, have led to the hypothesis that chemical composition of steels to be welded in a protective hydrogen atmosphere greatly affects their weldability; that chemistry restrains cracking of many steels; that dispersion of carbides in and around the weld zone permits escape of entrapped hydrogen which causes cracking. Low-hydrogen electrodes are generally preferable. Experiments by Battelle toward controlling porosity by surrounding the hydrogen arc with a bath of carbon monoxide have had promising results.

CORROSION CONTROL
PROTECTS INDUSTRY
NATIONAL ASSOCIATION OF CORROSION ENGINEERS
ORGANIZED

Corrosion News Section

PERSONALS

H. B. Higgins, president of the Pittsburgh Plate Glass Co., Pittsburgh, Penna., has been elected a director of the Crucible Steel Company of America, it was announced by William P. Snyder, Jr., chairman of the Crucible Steel Company of America, New York.

H. P. Munger has been appointed superintendent of the tin finishing department of the Youngstown Sheet & Tube Company's Indiana Harbor, Indiana, works. He was formerly metallurgist of the company's Youngstown, Ohio, plant.

L. C. Tingwall, Sr., has resigned from the Revere Copper & Brass Company, New York, to accept appointment as the engineering consultant for the Intercontinental Engineers, Inc., of Chicago. A recent member of the general office engineering staff of Revere, Mr. Tingwall had supervised the engineering and equipping of the company's new brass mill in San Paulo, Brazil, since the war.

Charles B. Grace, vice president and treasurer, Heintz Manufacturing Company, Philadelphia, Penna., has been elected a member of the board of directors of the Pennsylvania Salt Manufacturing Company of Philadelphia.

Robert G. Schock has joined the Chemical Section of the INCO Nickel Alloys Department of the International Nickel Company, Inc., in New York City, as a sales engineer concentrating on brewery and distillery equipment and parts.

Mr. Schock has been associated with Schock, Gusmer & Co., Hoboken, N. J., since 1933.

Harry W. McQuaid announced his resignation from Republic Steel Corporation to establish consultant services in Cleveland, Ohio, covering process and product development. Mr. McQuaid had been with Republic Steel since 1933, and was made assistant chief metallurgist in 1935. More recently, he has been manager of the process and product development division of that corporation in Cleveland.

Wilson A. Wright has been appointed manager of Sheet and Strip Sales, Republic Steel Corporation, Cleveland, Ohio, succeeding John W. Carpenter, who resigned due to ill health. Mr. Wright joined Republic Steel in 1930, in Youngstown, as a special representative in the Sheet & Strip Sales Division, and in 1933 was assigned to the Cincinnati area. In 1937, he was named district representative for Louisville, and in 1942 returned to Cincinnati as assistant district sales manager. In 1944, he was sent to Cleveland as assistant manager of the Sheet & Strip Sales division.

NEW PRODUCTS

The Dow Chemical Company, Midland, Michigan, announces a new aqueous-forming material that holds special interest for the paint, paper and textile industries. Called Dow Latex 512, it provides an immediate source of supply to those industries facing current shortage of supplies of edible vegetable oils, such as linseed.

The new material is a combination of styrene and butadiene, which, when air dried, forms a rubbery film with excellent pigment binding properties and a high protective value, the company claims. The new product is in production and available in 55-gallon steel drums, and tank cars.

Allen B. DuMont Laboratories, Inc., Passaic, N. J., have developed the Ferrorograph, an electronic device that enables comparing of ferrous materials as to chemical analysis and heat treatment. The instrument, based on correlation between magnetic and metallurgical properties, makes possible the determination of composition and condition of materials by magnetic testing, with a cathode-ray tube as the instantaneous indicator.

Enthone, Inc., New Haven, Conn., have developed an alkali cleaner called Enthone Brass Cleaner. This cleaner is said to have high detergent ability and, in addition, to have no tarnish action on active metals, including brass, copper, bronze, nickel silver, tin and lead, and can be used as a general plating-room cleaner for cleaning steel besides those metals listed.

A new spray-type machine for continuous pickling and washing of any metal part requiring surface preparation for the application of enamel or metallic coatings or for the removal of scale is announced by H. C. Klein, manager, Industrial Products Sales Division of The B. F. Goodrich Co.

Each unit is designed individually to suit the particular manufacturing problem and is lined with rubber by the company's Vulcalock process of adhering rubber to metal. The machine is said to have been used successfully for pickling cartridge cases and preparing steel hollow-ware for enameling. Among advantages cited by the company for the machine over the dip method are: straight line operation, with materials requiring minimum handling being fed into the conveyor feeding into the machine and carried automatically through each pickling and washing operation without intermediate handling; standardized production, with no special equipment being required for handling pieces of different shapes and sizes, the conveyor carrying any size or shape within the over-all size limits of the unit.

Flexibility of operation is possible, as the unit can be designed to fit almost any requirements, with different sizes and varying numbers of compartments for washing and pickling solutions.

Greater safety in operation is claimed through confinement of all acid and acid fumes in the chamber.

GENERAL INTEREST

R. B. Mears, Research Laboratory, U. S. Steel Corporation, Kearny, New Jersey, Chairman of the Program Committee for this year's NACE Conference and Exhibition to be held at the Palmer House, Chicago, April 7-10, advises that the Technical Program to be presented is fast taking shape. Eleven papers are already definitely scheduled for the various symposiums, and fifteen others are under consideration for acceptance. Over 30 papers will be presented during the four-day session, including the following symposiums: Cathodic Protection, Chemical Industry, Communications, Electrical Industry, Gas Industry, General Industry, Oil Industry, and the Water Industry.

Other important committee members are Arthur Smith, Jr., Manager, Cathodic Protection Sales Department, Dow Chemical Company, Midland, Michigan, Chairman of the Exhibits Committee, with L. A. Baldwin, of Johns-Manville Company, New York, and Hugh Baird, 630 West Meyer Blvd., Kansas City, Mo., co-chairman; M. G. Fontana, Ohio State University, Columbus, Ohio, is co-chairman with Dr. Mears of the Program Committee; J. J. Clancy, Wailes Dove-Hermiston Corporation, 105 W. Adams St., Chicago, is Chairman of the Publicity and Attendance Committee. Co-chairman is J. C. Stirling, of the Stanolind Pipe Line Company, P. O. Box 591, Tulsa, Okla. L. G. Vande Bogart heads the Hotel and Meeting Rooms Arrangement Committee. He can be reached at The Crane Company, 836 S. Michigan Avenue, Chicago. Mark Burlingame heads the Registration and Information Committee. His address is care of the Natural Gas Pipe Line Company, 20 North Wacker Drive, Chicago.

F. R. Arnoldy, Secretary of the Northeast Regional Division of NACE, reported a heartening response for the recent meeting and luncheon held by the Division in the Pennsylvania Hotel, New York. There were approximately 100 members and visitors present. Two excellent papers were presented and discussed, and aroused much interest. L. B. Donovan, of the Consolidated Edison Company, presented a movie entitled "Painting Gas Holders," which held the watchers, and much discussion followed its showing. G. R. Olson United Gas Pipe Line Company, also presented a movie entitled "Installing Cathodic Protection on Pipe Lines in Louisiana." The papers presented were "Non-Destructive Methods of Determining Extent of Wall Thinning," a paper on which B. G. Crabe, of Ethyl Corporation, and J. G. Kerley, of Shell Oil Company, had collaborated, while V. J. Albano and Robert Pope, of Bell Telephone Laboratories, drew up the article, "Protective Coating on Bell System Cables," for presentation. Mr. Arnoldy also reported that a great number of the non-members who attended the meeting submitted application for membership in

NACE. The next regional meeting will be held in Philadelphia at a future date yet to be selected.

The following members of NACE played important roles in the API meeting held in Chicago, November 11 through 14:

L. G. Scherer, chairman of Subcommittee on External Corrosion Mitigation (Pipe Line).

R. A. Brannon, past president of NACE, and chairman of API's Subcommittee of Topical Committee on Pipe Line Technology.

Henry K. Phipps and Ivy M. Parker presented papers to the Topical Committee on the methods of control of corrosion by products in pipe lines by (1) dehydration and (2) use of corrosion inhibitors.

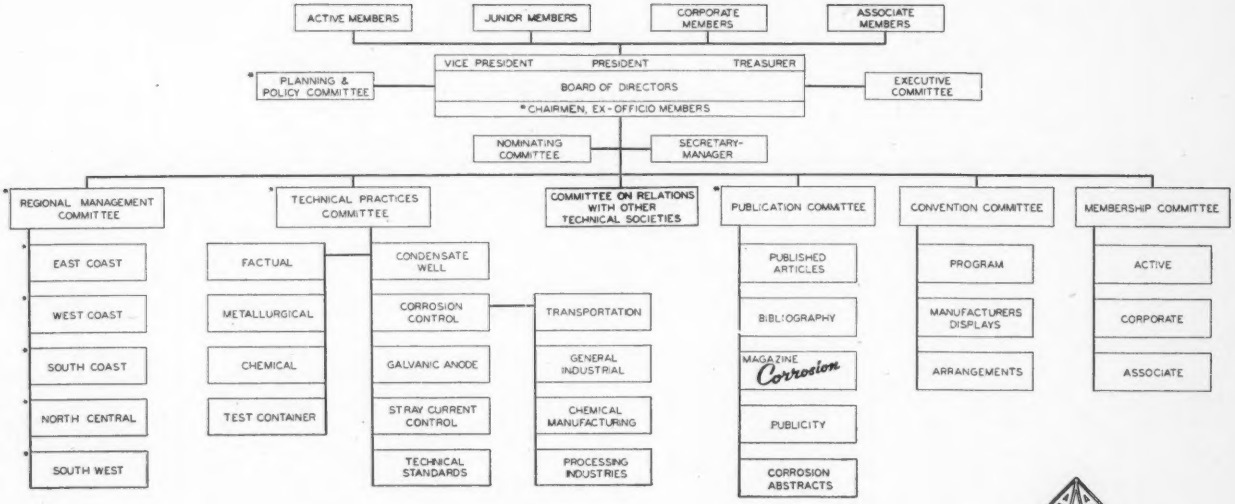
Dr. William A. Mudge, assistant director of the Technical Service Section of The International Nickel Company's Development and Research Division, New York, was one of the principal speakers at the recent meeting held in West Virginia of the Central Appalachian Section of the American Institute of Mechanical and Metallurgical Engineers. Dr. Mudge gave a very constructive talk on the manufacture and use of nickel and its alloys, and their chemical and mechanical properties.

American Chemical Society, New York, has been notified by Dr. Marston T. Bogert, of Columbia University, that 21 nations will participate in the rebuilding of the International Union of Chemistry. The union, of which Dr. Bogert is president, was suspended during the recent war.

The Tennessee Gas and Transmission Company has applied to the Federal Power Commission for permission to increase the capacity of its natural gas pipeline by 219,000,000 cubic feet daily, half of which will be furnished by waste flare gas in the Gulf Coast area. To accomplish the increase, Tennessee has also requested permission from FPC to install new compressor units totalling 81,600 horsepower; and to construct 681.1 miles of 26-inch loop, 68.7 miles of 24-inch loop and 82.4 miles of 20-inch loop along its 1265-mile, 24-inch line, which runs from South Texas to West Virginia. The contemplated expansion program will cost approximately $59,545,000. The company hopes to begin work on the project the latter part of June this year. The latest developments in corrosion control equipment, material and services will be utilized to protect the line against all known types of deterioration.

Shell Chemical Corporation, subsidiary of Shell Union Oil Company, New York, has announced plans to expand its chemical plant in Houston, Texas, at a cost of about $25 million. Facilities, when completed, will produce more than the combined outputs of the company's four West Coast plants.

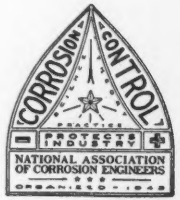
Zinc-lead ore reserves of the Tri-State district of Kansas, Oklahoma and Missouri are estimated at nearly 51 million tons of mineable ore, valued at about $171 millions, based upon current prices, according to a report by the Bureau of Mines. Although only 6,569,000 tons of new reserves were added in the district in 1944 and 1945, 16,587,000 tons were mined, the report shows.



Organization Chart

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

AN ASSOCIATION OF AND FOR ALL INDIVIDUALS ACTIVELY ENGAGED IN CONTROLLING, AND ORGANIZATIONS CONCERNED WITH, CORROSION OF METALLIC STRUCTURES



A. N.
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L. A.
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F. J.
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G. R.
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DIRECTORY
National Association of Corrosion Engineers

General Offices, Southern Standard Bldg., Houston 2, Texas

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Panhandle-Eastern Pipe Line Co.
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Texas Pipe Line Co.
Houston, Texas

L. G. Vande Bogart
Crane Company
Chicago, Ill.

Geographical Roster, Membership of NACE

As of December 15, 1946

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Parker, Walter A.
Southern Natural Gas Co.
Watts Bldg.
Ramsey, Jack W.
Southern Telegraph & Telephone Co.
Phoenix Bldg.
Yeldell, J. W.
Southern Natural Gas Co.
Box 2563

WILSON DAM
Tait, Emmitte P.
Tennessee Valley Authority

ARKANSAS

CARLISLE
Lowther, G. B.
Mississippi River Fuel Corporation
Box 142

EL DORADO
Hardcastle, Coy A.
Lion Oil Refining Co.
Exchange Bldg.
Rogerson, J. B.
Lion Oil Refining Co.
Exchange Bldg.

FORT SMITH
Ullrich, A. H.
City of Fort Smith
Water Department
City Hall

CALIFORNIA

AVENAL
Knowlton, Drexel R.
Kettleman North Dome Assn.
Bin C

AZUSA
Stromsoe, Douglas A.
Southern Pipe & Casing Co.
Box C

BAKERSFIELD
Smith, Clair J.
Western Gulf Oil Co.
Box 471

BELL
Schilling, W. M.
Southern Counties Gas Co.
4818 Beck Ave.

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Shell Development Co.
1833 Berryman St.
Jurs, Peter C.
Shand & Jurs Co.
917 Carlton St.

EMERYVILLE
Brady, Merritt H.
4245 Hollis St.
Breitenbach, Paul
Pacific Gas & Electric Co.
4245 Hollis St.
Dean, Roy O.
Pacific Gas & Electric Co.
4245 Hollis St.
Eldredge, George G.
Shell Development Co.
4560 Horton St.
Finley, Dozier
The Paraffine Cos., Inc.
1550 Powell St.
Schneider, Wm. R.
Pacific Gas & Electric Co.
4245 Hollis St.
Wachter, Aaron
Shell Development Co.
4560 Horton St.

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Phillians, T. F.
40-21st St.

INGLEWOOD
Gregory, Charles N., Jr.
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LONG BEACH
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Richfield Oil Corp.
Box 470
Kartinen, Ernest O.
2501 Willow St.

LOS ANGELES
Atkin, Howard P.
The Dow Chemical Co.
634 S. Spring St.
Bechtold, Ira C.
The Fluor Corp., Ltd.
2500 S. Atlantic Blvd.
Bradfield, S. A.
Southern California Gas Co.
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Cates, Walter H.
Western Pipe & Steel Co. of California
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Corfield, Guy
Southern California Gas Co.
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Dietze, Irwin Charles
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Doolittle, Fred B.
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Hall, Elwin B.
E. B. Hall & Co.
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Hiskey, D. R.
Dearborn Chemical Co.
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Keeling, Harry J.
Southern Counties Gas Co. of California
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O'Leary, F. J.
Barrett Division Allied Chem. & Dye Corp.
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Scott, Gordon N.
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Senatoroff, N. K.
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Stauffacher, E. R.
Southern California Edison Co., Ltd.
Box 351
Stevenson, Ralph Austin
641 Gibbons St.
Supple, George H.
General Petroleum Corp.
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Vail, Harold P.
Metropolitan Water District of Southern California
306 W. Third St.
Young, Garth L.
Signal Oil & Gas Co.
811 W. Seventh St.

MORRO BAY
Lawrence, William Harris
Valley Pipe Line Co.
Box 217

NORTH HOLLYWOOD
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OAKLAND
Knopp, Harold P.
Electrical Facilities, Inc.
4224 Holden St.

PASADENA
Pomeroy, Richard
Montgomery & Pomeroy
117 E. Colorado

RICHMOND
Putnam, Joseph F.
California Research Corp.

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Electric Bldg.
Rogness, E. C.
Civic Center Bldg.

SAN FRANCISCO
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310 Sansome St.
Farwell, Milo S.
Bethlehem Steel Co.
20th & Illinois Sts.
Howell, R. P.
Standard Oil Co. of California
225 Bush St.

SOUTH GATE
Munger, Charles G.
American Pipe & Construction Co.
4635 Firestone Blvd.

TRACY
Davie, Frank E.
Shell Oil Co., Inc.
Box 329

WILMINGTON
Michaud, M. L.
Union Oil Co. of California
Los Angeles Refinery

COLORADO

COLORADO SPRINGS
Abbott, Charles B.
Colorado Interstate Gas Co.
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McClintock, Robert D.
Colorado Interstate Gas Co.
Box 1087

DENVER
Burnett, Graydon E.
Bureau of Reclamation
New Custom House
Chadwick, H. M.
California Corrugated Culvert Co.
Box 2170
Fry, Frank B.
Public Service Co. of Colorado
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Garrett, G. H.
Thompson Pipe & Steel Co.
Box 2369

Gilliland, John L., Jr.
Bureau of Reclamation
New Custom House
Miller, Donald J.
Public Service Company of Colorado
900 15th St.

CONNECTICUT

HARTFORD
Hamilton, Archer B.
The Hartford Gas Co.
233 Pearl
NEW HAVEN
Meyer, Frederick R.
Southern New England Telegraph & Telephone Co.
227 Church St.
WATERBURY
Mitchell, N. W.
Chase Brass & Copper Co.
236 Grand St.
Nole, Vito F.
Chase Brass & Copper Co.
236 Grand St.
Price, David W.
Connecticut Light & Power Co.
250 Freight St.
Tracy, Arthur W.
The American Brass Co.

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Wells, David F.
Gates Engineering Co.
82 E. Franklin St.
WILMINGTON
Dill., Colby, Jr.
Gates Engineering Co.
200 W. Ninth St.
Maxwell, H. L.
E. I. du Pont de Nemours & Co.

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Cast Iron Pipe Research Assn.
National Bureau of Standards
Shepard, E. R.
5425 Connecticut Ave.

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Denoon, E. M.
South Florida Test Service
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Frink, Joe
Florida Power & Light Co.
Box 3100

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Britton, H. B.
Plantation Pipe Line Co.
Box 1743
Bull, Irving Stuart, Jr.
Georgia Tech.
Box 2173
Burdsal, A. J.
Southern Bell Telephone & Telegraph Co.
Chief Engineer's Office
Cauthen, Hydrick W.
Georgia Power Co.
127 Butler St. S.E.
Hereford, Arthur J.
465 Ponce De Leon Ave. N. E.
Nelson, Alan C.
Plantation Pipe Line Co.
Box 1743
Winters, B. W.
Southeastern Pipe Line Co.
Forsyth Bldg.
BREMEN
Parker, Ivy M.
Plantation Pipe Line Co.
Box 266

IDAHO

BOISE
Waterman, Howard E.
Idaho Power Co.
Box 770

ILLINOIS

BELLWOOD
Benman, James M.
Jeferson Electric Co.
25th Avenue & Madison St.
BROOKFIELD
Hart, Morris B.
4411 Du Bois Ave.
CHICAGO
Abbey, Oscar A.
Standard Oil Co. of Indiana
910 S. Michigan Ave.
Alk, Lewis C.
James B. Clow & Sons
Box 6600A
Bartlett, Harold J.
The Crane Company
836 S. Michigan Ave.
Bialosky, Jerome M.
Armour Research Foundation
35 W. 33rd St.
Biddison, P. McDonald
135 S. La Salle St.
Boberg, Irving E.
Chicago Bridge & Iron Co.
1305 W. 105th St.
Buell, James H.
Middle West Service Co.
20 N. Wacker Drive
Burlingame, M. V.
Natural Gas Pipeline Co.
20 N. Wacker Drive
Casey, J. Pat., Jr.
The Crane Company
836 S. Michigan Ave.
Clancy, J. J.
Wailes Dove-Hermiston Corp.
105 W. Adams St.
Converse, E. M.
Dearborn Chemical Co.
310 S. Michigan Ave.
Farkas, Martin Donald
The Sherwin Williams Co.
115th St. & Cottage Grove Ave.
Foelsch, Henry W.
1802 Byron St.
Glass, Dean C.
The Pure Oil Co.
35 E. Wacker Drive
Goldsby, Fred L.
Chicago Bridge & Iron Co.
1305 W. 105th St.
Greve, Lyman F.
Commonwealth Edison Co.
72 W. Adams St.
Haering, Vera W.
D. W. Haering & Co., Inc.
205 W. Wacker Drive
Lieber, Eugene
Nox-Rust Chemical Corp.
3429 S. Halsted St.
Loudenback, Clyde I.
Dearborn Chemical Co.
310 S. Michigan Ave.
Lynch, Raymond P.
Chicago District Pipeline Co.
122 S. Michigan Ave.
MacDonald, Frank P.
Electro Rust-Proofing Corp.
407 S. Dearborn St.
McDonald, Hugh J.
Corrosion Research Laboratory, Illinois Institute of Technology
3300 Federal St.
McGrue, W. M.
Atlas Lumnite Cement Co
10231 S. Prospect Ave.
McLeod, Raymond H.
The Dow Chemical Co.
135 S. La Salle St.
Morse, Arley Edwin
The Dow Chemical Co.
135 S. La Salle St.
Payton, Victor J.
Commonwealth Edison Co
72 W. Adams St.
Perry, Russell I.
Commonwealth Edison Co.
72 W. Adams St.
Ranta, Leo G.
Chicago District P. L. Co.
122 S. Michigan Ave.
Roberts, K. G.
Barrett Division
Allied Chemical & Dye Corp.
1400 Lake Shore Drive
Routson, L. B.
Western Union Telegraph Co.
427 S. La Salle St.
Schmitz, Carl Edward
Crane Packing Co.
1800 Cuyler Ave.
Seidel, G. E.
Amercoat Division
American Pipe & Construction Co.
4554 N. Broadway
Sheridan, S. A.
Armour Research Foundation
35 W. 33rd St.
Shoan, Raymond A.
Dearborn Chemical Co.
1029 W. 35th St.
Smith, Carl B.
Dearborn Chemical Co.
310 S. Michigan Ave.
Starmann, George H.
2537 W. Taylor St.
Strothman, E. P.
A. O. Smith Corp.
310 S. Michigan Ave.
Svrchek, Joseph G.
Dearborn Chemical Co.
310 S. Michigan Ave.
Underwood, O. G.
United Chromium, Inc.
6751 Oglesby Ave.
Vande Bogart, L. G.
The Crane Company
836 S. Michigan Ave.
Van Loo, Maurice
The Sherwin-Williams Co.
115th St. & Cottage Grove Ave.
Yeazel, F. C.
Reilly Tar & Chemical Corp.
2513 S. Damen Ave.
Ziemann, Clarence L.
Lithgow Corp.
333 W. 40th Place
DECATUR
Bowan, Walter J.
Mueller Company
EAST ST. LOUIS
Heideman, William A.
Socony-Vacuum Oil Co., Inc.
S. 20th St.
EVANSTON
Bohne, A. W.
The Tapecoat Co.
1521 Lyons St.

McGee, Herbert S.
2522 Noyes St.
Ronningen, H. A.
Ronningen Engineering Sales
1803 Chicago Ave.

KANKAKEE
Higgins, Waldo W.
A. O. Smith Corp.

McCOMB
Kettron, Henry P.
Illinois Electric Porcelain Co.
510 Pearl St.

MAYWOOD
Weaver, H. E.
Public Service Co. of Northern Illinois
1319 S. First Ave.

NORTHFIELD
Jackson, Maynard H.
Hill, Hubbell & Co.
Division of General Paint Corp.
251 Wagner Road

OAK PARK
Jensen, O. L.
Public Service Co. of Northern Illinois
1001 S. Taylor Ave.
Nichols, Laurie E.
Public Service Co. of Northern Illinois
1001 S. Taylor Ave.

PEORIA
Blaine, Russel K.
Hiram Walker & Sons, Inc.
Foot of Edmund St.

URBANA
Andrews, Andrew I.
Department of Ceramic Engineering
University of Illinois
Wainwright, Ray M.
Department of Electrical Engineering
University of Illinois

INDIANA

EVANSVILLE
Berry, Norton E.
Servel, Inc.
119 N. Morton Ave.

HAMMOND
Leeds, Donnelly A.
Northern Indiana Public Service
5265 Homan Ave.

INDIANAPOLIS
Higburg, William
Reilly Tar & Chemical Corp.
Merchants Bank Bldg.
Honecker, Walter C.
Indiana Bell Telephone Co.
240 N. Meridian

TERRE HAUTE
Bachman, Paul W.
Commercial Solvents Corp.

ZIONSVILLE
Berringer, John C.
Panhandle Eastern Pipe Line Co.
Box 231
Johnson, J. F., Jr.
Shell Oil Co., Inc.
Drawer A

IOWA

COUNCIL BLUFFS
Lawrenz, Milton M.
National Cooperative Refinery Assn.
South Omaha Road

DAVENPORT
Smith, Olin K.
United Light & Power Service Co.
United Light Bldg.

KANSAS

ABILENE
Murray, W. J.
Central Gas Utilities Co.
304 N. Cedar

AUGUSTA
Bedell, H. L.
Socony-Vacuum Oil Co., Inc.
White Eagle Pipe Line Division

BURRTON
Pettijohn, Dale S.
Panhandle Eastern Pipe Line Co.
R. R. 2

INDEPENDENCE
Fell, Paul D.
Sinclair Refining Co.
Box 460

LIBERAL
Graber, Waldo E.
Panhandle Eastern Pipe Line Co.
Box 979

McPHERSON
Roberts, Louis E.
National Cooperative Refinery Assn.
Box 770

MANHATTAN
Rohrman, F. A.
Kansas State College

NEODESHA
Gear, Harry C.
Box 240

PITTSBURG
Miller, Ralph D.
Spencer Chemical Co.
Box 604
Woodward, Henry F., Jr.
Spencer Chemical Co.
Box 604

WICHITA
Begole, Edgar Ray
2022 N. Green St.
Corey, Bruce L.
Socony-Vacuum Oil Co.
Box 1882
Dickinson, L. R.
Socony-Vacuum Oil Co.
White Eagle Pipe Line Division
First National Bank Bldg.
Johansen, Irving H.
Socony-Vacuum Oil Co.
Box 1882
Rupf, J. Albert
Socony-Vacuum Oil Co.
Box 1882
Smith, William N.
Wood River Oil & Refining Co.
335 W. Lewis St.
Stephens, E. H.
Westinghouse Electric Corp.
233 S. St. Francis
Sutter, Carl H.
Kansas Gas & Electric Co
Box 208

KENTUCKY

ASHLAND
Brumer, Max
1502 29th St.

LEXINGTON
Coffinberry, Arthur S.
University of Kentucky
Department of Metallurgical Engineering

LOUISVILLE
Schneider, R. W.
Nokem Engineering Co., Inc.
216 W. Washington St.

LOUISIANA

BATON ROUGE
O'Brien, Paul S.
Socony Paint Products Co.
630 Laurel St.

COTTON VALLEY
McGuire, T. W.
Cotton Valley Oprs. Committee
Box 1008

LAKE CHARLES
Schofer, Nathan
Cities Service Refining Corp.
Tutwiler Refinery

MONROE
Givens, Allen T.
Southern Gas Line, Inc.
Drawer 1562
Roddey, Otha C.
Interstate National Gas Co.
Box 1482

NEW ORLEANS
Besse, Celestine Paul
The California Co.
Canal Bldg.
Gaidry, H. L.
New Orleans Public Service, Inc.
317 Baronne St.
Ireland, L. G.
New Orleans Public Service, Inc.
317 Baronne St.
Kuhn, Robert J.
Pere Marquette Bldg.
Rhodes, G. L.
New Orleans Public Service, Inc.
317 Baronne St.
Trouard, Sidney E.
New Orleans Public Service, Inc.
317 Baronne St.

PORT SULPHUR
Monroe, J. E., Jr.
Freeport Sulphur Co.

SHREVEPORT
Abernathy, M. A.
United Gas Pipe Line Co.
Box 1407
Arthur, H. M.
Atlas Oil & Refining Corp.
Box 1607
Atkins, Emery Loe
United Gas Pipe Line Co.
Box 1407
Babcock, L. F.
Arkansas Fuel Oil Co.
Slattery Bldg.
Beezley, H. V.
United Gas Pipe Line Co.
Box 1407
Bennett, H. R.
Union Producing Co.
Box 1407
Broome, W. A.
Arkansas Louisiana Gas Co.
Slattery Bldg.
Chandler, P. J.
Arkansas Louisiana Gas Co.
Box 1734
Cornett, W. J.
United Gas Pipe Line Co.
Box 1407
Evans, C. W.
United Gas Pipe Line Co.
Box 1407
Greco, Edward C.
United Gas Pipe Line Co.
Box 1407
Griffin, H. T.
United Gas Pipe Line Co
1515 Fairfield Ave.
Griggs, Henry P.
857 Stephenson
Holcombe, Tom L.
Dearborn Chemical Co.
324 Ardis Bldg.
Kendrick, J. L.
United Gas Pipe Line Co.
Box 1407
Levert, William F.
United Gas Pipe Line Co.
Box 1407
McDonald, T. B.
United Gas Pipe Line Co.
Box 1407
Olson, G. R.
United Gas Pipe Line Co.
Box 1407

Ringer, Francis
Intersate Oil Pipe Line Co.
Box 1107
Schlather, Max F.
United Gas Pipe Line Co.
Box 1407
Spinks, Lee N.
United Gas Pipe Line Co.
Box 1407
Stearns, D. E.
Box 1234
Sullivan, E. H.
United Gas Pipe Line Co.
Box 1407
Wilkes, Frank M.
Southwestern Gas & Electric Co.

SULPHUR
Clarke, F. Tackett
Union Sulphur Co., Inc.

MARYLAND

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Allen, J. E.
Pennsylvania Water & Power Co.
1611 Lexington Bldg.
Darrin, Marc
Mutuel Chemical Co. of America
1348 Block St.
Huston, Kenneth M.
Rustless Iron & Steel Co.
3400 E. Chase St.
Lill, John R.
732 Charing Cross Road
Powell, Sheppard T.
330 N. Charles St.
Sample, Clarence H.
501 W. University Parkway
Wolf, Edgar F.
Consolidated Gas Electric Light & Power Co. of Baltimore
531 E. Madison St.
Zeidler, William H.
4801 Richard Ave.

BETHESDA
Farrar, Walter B.
5011 Elm St.

MASSACHUSETTS

BOSTON
Cushing, Daniel
148 State St.
Troupe, Ralph A.
Dept. of Chemical Engineering
Northeastern University
Tsunoda, Kenneth
Artisan Metal Products, Inc.
211 Congress St.
Wood, Paul E.
Tungar & Metallic Rectifier Division
General Electric Co.
140 Federal St.

CAMBRIDGE
Davis, F. W.
E. B. Badger & Sons Co.
260 Bent St.

QUINCY
Mosher, Lloyd Malcolm
Shipbuilding Division
Bethlehem Steel Corp.

SOUTH BOSTON
Sherwood, William C.
Hershey Manufacturing Co.
Corner E & Second Sts.

WALTHAM
Karraker, Ed. L.
Shell Oil Co., Inc.
Box 181

WATERTOWN
Jacobson, Murray
Watertown Arsenal

MICHIGAN

DETROIT
Clayton, William J.
Adhesive & Coating Div.,
Minnesota Mining & Mfg. Co.
411 Piquette Ave.
Fraser, William R.
Michigan Consolidated Gas Co.
415 Clifford
Sanderson, Wiley D.
The Detroit Edison Co.
2000 Second Ave.
Saulson, Saul
Albert Kahn Associated Architects and Engineers
345 New Center Bldg.
Walker, Henry S.
The Detroit Edison Co.
2000 Second Ave.

JACKSON
O'Brien, Thomas W.
Consumers Power Co.
212 Michigan Ave.

MIDLAND
Colburn, Lyle W.
The Dow Chemical Co.
Hunter, Ralph M.
1108 East Park Drive
Robinson, Harold A.
Physical Research Laboratory
The Dow Chemical Co.
Robinson, Melvin O.
The Dow Chemical Co.
Smith, Arthur, Jr.
Cathodic Protection Sales Dept.
The Dow Chemical Co.
Yarrington, Donald M., Jr.
Physical Research Laboratory
The Dow Chemical Co.

SAGINAW
Featherly, Robert L.
2559 N. Bond St.

TRENTON
Hickey, Robert Percy
Socony-Vacuum Oil Co., Inc.
Drawer D

WAYNE
Sexton, Whitney G.
Ohio-Michigan Pipeline Div.
Box 231

MINNESOTA

MINNEAPOLIS
Jacobs, M. L.
Jacobs Wind Electric Co.
2111 Washington Ave. N.
Mann, Charles A.
Dept. of Chemical Engineering
University of Minnesota
Neprude, E. N.
City of Minneapolis Water Dept.
City Hall
Patterson, M. Kingsley
Minneapolis Gas Light Co.
739 Marquette Ave.

MISSISSIPPI

JACKSON
James, H. E.
Mississippi Power & Light Co.
Box 1640
Jones, G. C.
Mississippi Power & Light Co.
Box 1640

MISSOURI

CARTHAGE
Carmichael, J. D.
Box 576

JOPLIN
Musgrave, John Reichert
Research Laboratory
The Eagle-Picher Co.
Box 290

KANSAS CITY
Black, Ernest B.
Black & Veatch
4706 Broadway
Busch, Paul E.
Great Lakes Pipe Line Co.
1500 Bryant Bldg.
Church, L. T.
Panhandle Eastern Pipe Line Co.
1221 Baltimore Ave.
Fowler, James A., Jr.
Panhandle Eastern Pipe Line Co.
1221 Baltimore Ave.
Hieronymus, T. G.
Kansas City Power & Light Co.
Box 679
McElhatton, Francis J.
Panhandle Eastern Pipe Line Co.
1221 Baltimore Ave.
Pyott, William T.
Great Lakes Pipe Line Co.
Box 2239
Stutzman, Milo J.
Midwest Research Institute
4049 Penn

ST. LOUIS
Dodd, George D.
Laclede Gas Light Co.
3950 Forest Park Ave.
Ferree, Ray J.
National Lead Co.
722 Chestnut St.
Lester, Charles B.
Sohio Pipe Line Co.
407 N. Eighth St.
Mange, Clarence E.
C. E. Mange Development Laboratory
4425 Geraldine Ave.
Nelson, Roland E.
H. K. Porter Co., Inc.
Paul Brown Bldg.
Rasmussen, V. L.
The Laclede Gas Light Co.
3950 Forest Park Ave.
Richards, Walter C.
A. Leschen & Sons Rope Co.
5909 Kennerly Ave.

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Dyer, W. S.
Ajax Pipe Line Corp.
Box 1246
Holland, J. B.
Ajax Pipe Line Corp.
Landers Bldg.

UNIVERSITY CITY
Dolson, Frank E., Jr.
St. Louis County Water Co.
6600 Delmar Boulevard

MONTANA

BUTTE
Davis, Carl R.
Montana Power Co.
40 E. Broadway

GLENDIVE
Williams, Ernest E.
Montana-Dakota Utilities Co.
Box 351

NEBRASKA

BEATRICE
Krueger, Jess J.
Northern Natural Gas Co.
1212 Elk St.

HASTINGS
Hill, Leonard Clarence
Kansas-Nebraska Natural Gas Co., Inc.
300 North St. Joe.

OMAHA
Klever, Charles F.
Metropolitan Utilities Dist.
18th & Harney Sts.

NEW JERSEY

BARBER
Reichord, Edmund C.
Central Research Laboratory
American Smelting & Refining Co.

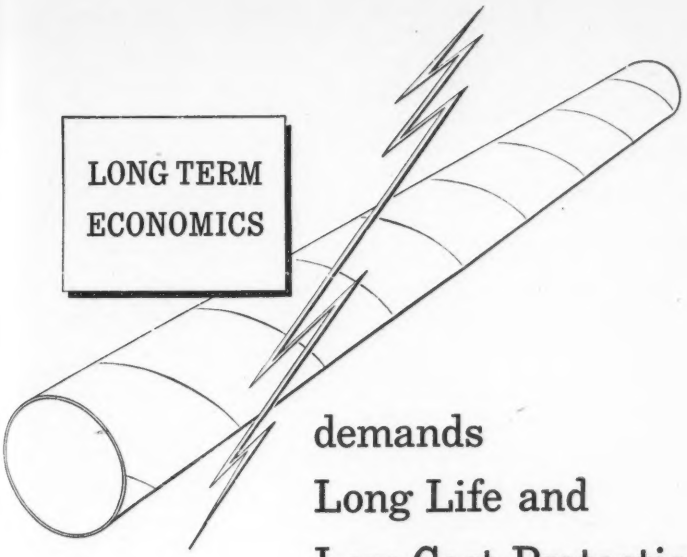
BAYONNE
Klinger, O. C.
Oildom Publishing Co.
1217 Hudson Blvd.
BURLINGTON
Schuh, Arthur E.
United States Pipe & Foundry Co.
ELIZABETH
Fyke, F. C.
Standard Oil Development Co.
Box 37
GRASSELLI
Thiede, Richard Conrad
General Aniline Works
HARRISON
Allen, Russell J.
Worthington Pump & Machinery Co.
MANVILLE
Barbehenn, Ralph L.
Research Laboratory
Johns-Manville Corp.
Clarvoe, George W.
Research Laboratory
Johns-Manville Corp.
MAPLEWOOD
Howell John C.
Public Service Electric & Gas Co.
200 Boyden Ave.
Pearson, E. T.
Testing Laboratory
Public Service Electric & Gas Co.
200 Boyden Ave.
NEWARK
Aldrich, Comdr. Harold L.
423 Ridge St.
Bonner, Walter F.
Federal Telephone & Radio Corp.
Box 690
Brooks, A. Sidney
Public Service Elec. & Gas Co.
80 Park Place
Collins, George J.
Federal Telephone & Radio Corp.
200 Mt. Pleasant Ave.
Hutton, Harold S.
Wallace & Tiernan Co., Inc.
Box 178
Macdonald, Forrest Ranald,
Electro Rust-Proofing Corp.
Box 178
Salmon, Philip A.
Public Service Electric & Gas Co.
80 Park Place
Sudrabin, Leon P.
Electro Rust-Proofing Corp.
Box 178
Wunderlich, Norman E.
Federal Telephone & Radio Corp.
200 Mt. Pleasant Ave.
NORTH ARLINGTON
Eberhardt, Ernest Theodore
Subox, Inc.
348 River Road
PASSAIC
Everest, Guy N.
Okonite Co.
PATERSON
Bennett, Charles E.
Okonite Callender Cable Co.
730 21st Ave.
Garrison, V. L.
Okonite Callender Cable Co.
730 21st Ave.
PHILLIPSBURG
Cann, Kenneth R.
Ingersoll-Rand Co.
Crobaugh, Albert O.
Ingersoll-Rand Co.
Godshall, J. Byron
Ingersoll-Rand Co.
TRENTON
Alexander, Robert O.
Thiokol Corp.
780 N. Clinton Ave.
WESTFIELD
Stromquist, Russell C.
Wailes Dove-Hermiston
Box 390
Thornhill, William H. T.
Wailes Dove-Hermiston Corp.
Box 390

NEW MEXICO

ALBUQUERQUE
Peacore, O. B.
Southern Union Gas Co.
Box 1692
CARLSBAD
Holt, James B.
International Minerals & Chemical Corp.

NEW YORK

BRIARCLIFF MANOR
Glass, Hyman Frank
Centro Research Laboratories, Inc.
Brandywine & Sleepy Hollow Road
Berman, Morton
Brookly Union Gas Co.
197 St. James Place
BROOKLYN
Diehlman, George
National Lead Co.
105 York St.
Goldsmith, Clarence S.
Brooklyn Union Gas Co.
176 Remsen St.
Kleinheksel, Stanley
Socony-Vacuum Oil Co.
415 Greenpoint Ave.
Thompson, Charles H.
New York Telephone Co.
101 Willoughby St.
Wilkinson, Horatio L.
DeBevoise Co.
968 Grand St.
Zahn, H. E.
National Lead Co.
105 York St.
BUFFALO
Nicholson, C. T.
Buffalo Niagara Electric Corp.
Electric Bldg.
FLUSHING
West, C. H.
157-11 Sanford Ave.
NEW YORK
Abrams, Milton F.
Wailes Dove-Hermiston Corp.
17 Battery Place
Andrew, Harold O.
Robbins Publishing Co.
9 East 38th St.
Arnoldy, Francis R.
American Telephone & Telegraph Co.
195 Broadway
Bagnell, William E.
Ebasco Services, Inc.
2 Rector St.
Baker, Henry F.
Baker Synthetics, Inc.
51 E. 42nd St.
Baker, Ralph D.
National Lead Co.
111 Broadway
Baldwin, L. A.
Johns-Manville Sales Corp.
22 E. 40th St.
Battle, Thomas J.
Wailes Dove Hermiston Corp.
17 Battery Pl.
Blenheim, Donald E.
American Telephone & Telegraph Co.
140 West St.
Boyd, George E.
Wailes Dove-Hermiston Corp.
17 Battery Place
Bruley, Robert W.
Wailes Dove-Hermiston Corp.
17 Battery Place
Church, Herbert M., Jr.
Lead Industries Association
420 Lexington Ave.
Cobb, Stephen P.
Ebasco Services, Inc.
2 Rector St.
Crane, Benjamin Gardner
Ethyl Corporation
405 Lexington Ave.
Dewey, William S.
New York Telephone Co.
140 West St.
Donovan, Lewis B.
Consolidated Edison Co.
4 Irving Place
Faires, Carl D.
Shell Oil Co., Inc.
50 W. 50th St.
Feller, Eugene W. F.
McGraw-Hill Publishing Co.
330 W. 42nd St.
Friz, Nelson
Standard Oil Co. of New Jersey
26 Broadway
Gorman, Lawrence J.
Consolidated Edison Co. of New York
4 Irving Place
Graham, S. B.
American Telephone & Telegraph Co.
195 Broadway
Gray, A. E.
Barrett Division
Allied Chemical & Dye Corp.
40 Rector St.
Hall, Kenneth G.
Barrett Division
Allied Chemical & Dye Corp.
40 Rector St.
Huntley, Harold R.
American Telephone & Telegraph Co.
195 Broadway
Jordan, Harry E.
American Water Works Assn.
500 Fifth Ave.
Kulman, Frank E.
Consolidated Edison Co. of New York, Inc.
4 Irving Place
Lain, George D.
American Iron & Steel Institute
350 Fifth Ave.
LaQue, F. L.
International Nickel Co., Inc.
67 Wall St.
Lee, James A.
Chemical & Metallurgical Engineering
330 W. 42nd St.
McComb, George B.
Barrett Division
Allied Chemical & Dye Corp.
40 Rector St.
Maitland, T. J.
American Telephone & Telegraph Co.
32 Sixth Ave.
Maurer, Keith L.
Bell Telephone Laboratories, Inc.
463 West St.



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Morton, Byron B.
International Nickel Co.
67 Wall St.
Noppel, E. P.
Ebasco Services, Inc.
2 Rector St.
Perry, Clifford Burgess
Westinghouse Electric International Co.
40 Wall St.
Peters, Fred P.
Reinhold Publishing Corp.
330 W. 42nd St.
Pettee, Allen D.
General Cable Corporation
420 Lexington Ave.
Pope, Robert
Bell Telephone Laboratories, Inc.
463 West St.
Rhodes, George I.
Ford, Bacon & Davis, Inc.
39 Broadway
Rinehart, Evan
Johns-Manville Corp.
22 E. 40th St.
Rose, William, Jr.
The Aquatec Corp.
545 Fifth Ave.
Ruffing, Frank M.
The Dow Chemical Co.
30 Rockefeller Plaza
Schmidt, Eugene
The Dorr Company
570 Lexington Ave.
Shaw, George E.
Oliver United Filters, Inc.
33 W. 42nd St.
Shuldener, Henry L.
Water Service Laboratories
423 W. 126th St.
Smith, Sydney S.
Shell Oil Company, Inc.
50 W. 50th St.
Standring, J. M., Jr.
American Telephone & Telegraph Co.
195 Broadway
Thalmann, E. H.
Ebasco Services, Inc.
2 Rector St.
Tour, Sam
Sam Tour & Co., Inc.
44 Trinity Place
Tice, E. Allen
International Nickel Co.
67 Wall St.
Van Houten, Leslie P.
American Telephone & Telegraph Co.
140 West St.
Vanick, James S.
International Nickel Co.
67 Wall St.
Voigt, Lorraine R.
International Nickel Co.
67 Wall St.
Wahlquist, Hugo W.
Ebasco Services
2 Rector St.
Walczak, M. R.
Barrett Division Allied Chemical & Dye Corp.
40 Rector St.
Zahniser, Arthur N.
Wailes Dove-Hermiston Corp.
17 Battery Place

NIAGARA FALLS
Shields, James E.
Alox Corporation
3943 Buffalo Ave.

ROCHESTER
Branson, Edward H.
General Railway Signal Co.
801 West Ave.

ROME
Lynes, Wilson
Revere Copper & Brass, Inc.

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Mengel, Arthur C.
American Locomotive Co.
North Jay St.

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Robson, Arthur D.
Toch Brothers, Inc.
2600 Richmond Terrace
Van Vliet, R.
New York & Richmond Gas Co.
691 Bay St.

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United States Stoneware Co.
Box 350

CINCINNATI
Goetz, Alvin C.
Eagle-Picher Company
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Knapp, Frederick F.
6508 Montgomery Road.
Malcolm, V.
Philip Carey Manufacturing Co.
Anthony Wayne Ave.
Pfeiffer, Milton J.
Cincinnati Gas & Electric Co.
Box 960

CLEVELAND
Bixby, Willard F.
B. F. Goodrich Chemical Co.
9th & Prospect Sts.
Bowen, Milton M.
Hill-Hubbell Division General Paint Corp.
3091 Mayfield Road.
Carson, John H.
East Ohio Gas Co.
1405 East Sixth St.
Craver, Albert F.
Cleveland Heater Co.
2310 Superior Ave.
Febrey, H. H.
American Steel & Wire Co.
614 Superior Ave., N.W.
Gosnell, Everett C.
Colonial Iron Works Co.
17643 St. Clair Ave.
Kerns, Everette E.
Standard Oil Co. of Ohio
Midland Bldg.
Loucks, Charles M.
Dowell, Inc.
Terminal Tower Bldg.
Martin, Wayne E.
National Smelting Co.
6700 Grant Ave.
Ricksecker, Ralph E.
Chase Brass & Copper Co., Inc.
1155 Babbitt Road
Schultz, Wayne H.
Hill, Hubbell Division General Paint Corp.
3091 Mayfield Road
Vandaveer, F. E.
East Ohio Gas Co.
Foot E. 63rd, N. of St. Clair
Whitacre, Charles H.
Standard Oil Co. of Ohio
1067 Midland Bldg.
Young, Robert J.
Hill, Hubbell Division General Paint Corp.
3091 Mayfield Road

COLUMBUS
Feldman, Karl T.
Sinclair Refining Co.
Huntington Bank Bldg.
Fontana, Mars G.
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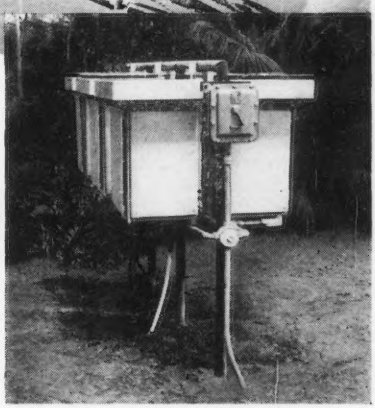

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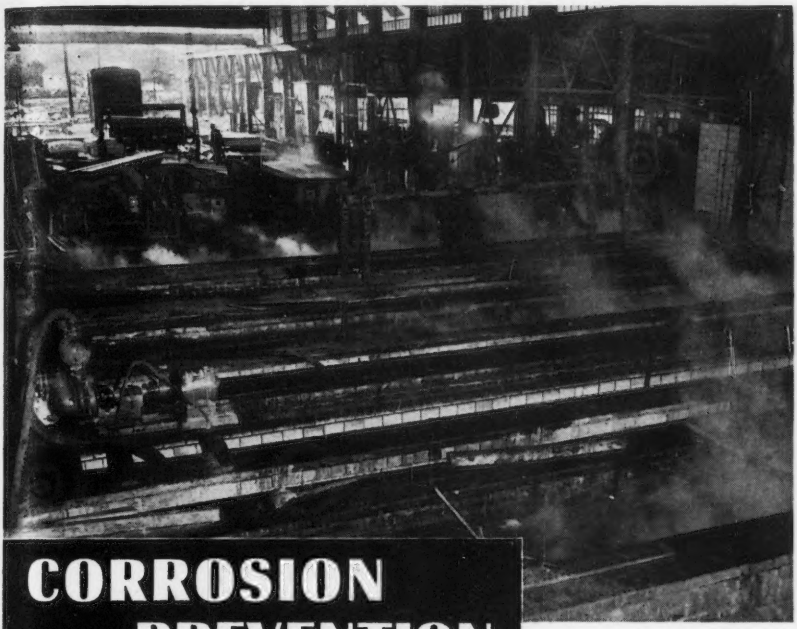

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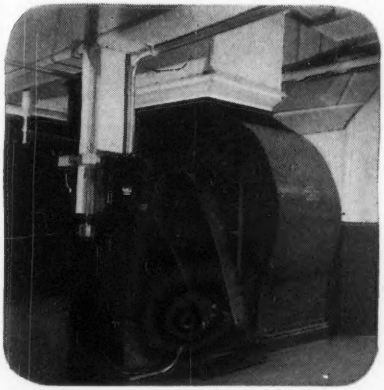

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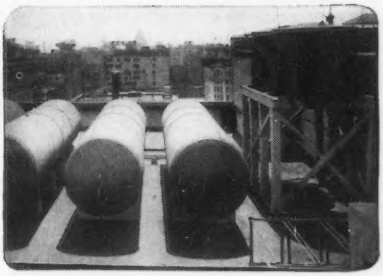

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MIAMI 36 SAN FRANCISCO 10 LOS ANGELES 1

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Osburn, E. R.
Texas-New Mexico Pipe Line Co.
Box 2332

Parker, M. E., Jr.
Pan-American Pipe Line Co.
Mellie Esperson Bldg.

Pecore, Albert E.
Humble Pipe Line Co.
Drawer 2220

Price, Walter J.
Port Commission
Civil Courts Bldg.

Rector, Paul F.
Humble Oil & Refining Co.
Route 13, Box 515

Robinson, T. J.
Bethlehem Supply Co.
7100 Clinton Dr.

Rogers, Walter F.
Gulf Oil Corp.
Drawer 2100

Rolfs, E. L.
Crutcher-Rolfs-Cummings
Mellie Esperson Bldg.

Ross, George T.
Houston Natural Gas Corp.
Petroleum Bldg.

Scamman, Charles W.
Houston Oil Field Material Co.
1422 Maury St.

Scherer, Lewis F.
Texas Pipe Line Co.
Box 2332

Sharpe, L. G.
4012 Chartres

Sheppard, Lyle R.
6522 Mercer St.

Smith, Alonzo L.
4012 Willowick Road

Spafford, Perry Parker
Stanolind Oil & Gas Co.
Box 3092

Stegner, A. L.
Tennessee Gas & Transmission Co.
Box 2511

Stephenson, James F.
Houston Pipe Line Div.
Gulf Refining Co.
Drawer 2100

Sullivan, R. J.
Humble Oil & Refining Co.
Box 2180

Sterrett, Elton
1948 Lexington

Thayer, Starr
Southern Standard Bldg.

Tisdale, O. R.
Tidal Pipe Line Co.
Box 1404

Turner, Delber W.
Petroleum Rectifying Co.
Box 2546

Tweedie, T. C.
Oil Well Co.
Mellie Esperson Bldg.

Williams, P. F.
Pan-American Pipe Line Co.
Mellie Esperson Bldg.

Wood, Herschel J.
Lebanon Steel Foundry
Commerce Bldg.

Waldrip, H. E.
Gulf Oil Corp.
Gulf Bldg.

Willson, J. P.
Houston Lighting & Power Co.
1016 Walker St.

Wood, Elgean I.
Westinghouse Electric & Mfg. Co.
2315 Commerce Ave.

Yates, Joseph Perkins, Jr.
Eastern States Petroleum Co., Inc.
Box 5008

Zajac, Ted S.
Shell Oil Co., Inc.
Box 2099

Zedler, Otto F.
Houston Pipe Line Division
Gulf Refining Co.
Drawer 2100

INGLESIDE

Roderick, Richard
Humble Pipe Line Co.

IRAAN

Shaeffer, David C.
Pasotex Pipe Line Co.
Box 428

JOINERVILLE

Graves, J. H.
Tidal Pipe Line Co.
Box 777

KATY

Gorden, C. D.
Humble Oil & Refining Co.
Box 276

KINGSVILLE

Sparks, Lt. Comdr. Robert E.
Public Works, Dept.
NAAS

KIRBYVILLE

Sawyer, S. E.

LUFKIN

Porter, Cover C.
Southland Paper Mills

MIDLAND

Lewis, L. G.
Standard Oil Co. of Texas
Petroleum Bldg.

MT. PLEASANT

Rook, C. G., Jr.
Talco Asphalt & Refining Division
American Liberty Oil Co.

NEDERLAND

Bedell, William S.
Smiths Bluff Refinery
Pure Oil Co.
Box 237

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Callahan, V. L.
Magnesium Division
International Mineral & Chemical Corp.
Box 552

Schultz, S. T.
The Texas Company
Box 712

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Atlantic Pipe Line Co.
Box 849

Strawn, Lynn Rudolph
The Texas Company

PORT NECHES

Traxler, Ralph N.
The Texas Company
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United Gas Pipe Line Co.
Box 421

TAFT

Yates, Louis N.
Box 576

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Pan American Refining Corp.
Box 401

Dodds, Dan L.
Republic Oil Refining Co.

Forbes, M. C.
Pan American Refining Corp.

Jewell, Edwin
Monsanto Chemical Co.
Box 1311

Millender, Joseph D.
Republic Oil Refining Co.

Pettyjohn, A. R.
Carbide & Carbon Chemicals Co.
Box 471

VAN

Wisdom, James Arno
Pure Transportation Co.
Box No. 25-W

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Allen, W. O.
United Gas Pipe Line Co.
Box 780

Gates, A. J.
City of Wichita Falls Municipal Auditorium

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Mountain Fuel Supply Co.
36 State St.

Gardner, G. Douglas
U. S. Bureau of Mines
1600 E. First St.

Purton, T. A.
Utah Power & Light Co.
Box 889

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Marquette University
2919 W. Juneau Ave.

Scheil, Merrill A.
A. O. Smith Corp.

RACINE

Brinen, Howard F.
Young Radiator Co.
709 S. Marquette St.

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Thomas, Ralph W.
Waukesha Foundry Co.
Lincoln Ave.

WYOMING

CASPER

Krueger, Louis T.
Northern Utilities Co. & North Central Gas Co.
441 S. Center St.

THERMOPOLIS

Satterfield, James L.
Mountain States Power Co.
Box 512

Foreign

AUSTRALIA

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Hopkins, Arthur James
Hume Steel, Ltd.
Box 4534
Longfield, C. M.
State Electricity
Commission of Victoria
22-32 William

CANADA

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Brownie, F. A.
The Canadian Western
Natural Gas, Ltd.,
Heat & Power Co., Ltd.,
215 6th Ave. W.
Mellon, P. D.
The Canadian Western
Natural Gas, Ltd.,
Heat & Power Co., Ltd.,
215 6th Ave. W.

MIMICO, ONTARIO
Thomas, John Frederick Jas.
Steel Pipe Research
Institute
66-A Superior Ave.

SARNIA, ONTARIO
Russell, Andrew
Imperial Oil, Ltd.
Christina St., South

SHAWINIGAN FALLS, QUE.
Shaw, George S.
Shawinigan Chemicals,
Ltd.

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Meagher, R. D.
British American Oil Co.,
Ltd.,
Royal Bank Bldg.

TRAIL, BRITISH COLUMBIA
Busby, A. H. Wilson
Consolidated Mining &
Smelting Co. of Canada,
Ltd.
Central Technology
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BALBOA HEIGHTS
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Box 957

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Kelly, Michael Everitt
Anglo-Iranian Oil Co., Ltd.
Britannic House, Finsbury
Circus

MEXICO

ROSITA, COAHUILA
Moyle, M. W.
Cia. Carbonifera de
Sabinas, S. A.

PUERTO RICO

HATO REY
Badrena, Fernando, Jr.
Phosphate & Acid Works
Division
Ochoa Fertilizer Corp.
Box 117

SOUTH IRAN

ABADAN
Ross, Kenneth Brebner
Anglo-Iranian Oil Co., Ltd.

VENEZUELA

MARACAIBO
Brannan, Albert Ira
Mene Grande Oil Co.
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Amador, Frank J.
Creole Petroleum Corp.
Apartado 172
Hackett, Albert Harold
Venezuelan Telephone Co.
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